INHIBITORY LANGUAGE DEFICITS IN ATTTENTION DEFICIT/HYPERACTIVITY DISORDER AND READING DISORDER: A CANDIDATE SHARED DEFICIT

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ABSTRACT

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Few studies have examined whether inhibition impairments in Attention Deficit/Hyperactivity Disorder (ADHD)—well-established in the motor output domain—extend to higher-order cognition such as language processing. This study explored whether inhibitory mechanisms that protect language comprehension are impaired in ADHD, and whether such inhibitory deficits, if they exist, clarify the etiology of the high rate of co-occurrence between ADHD and Reading Disorder (RD). Two language comprehension tasks from the cognitive literature believed to probe inhibitory mechanisms were used: 1) a sentence-level lexical ambiguity meaningful judgment task that measured interference control, and 2) a syntactic garden path revision task which examined ability to use semantic cues to revise misinterpretations "on-line" during sentence comprehension.

97 children aged 7 to 14 with ADHD or RD participated in the study after thorough diagnostic assessment with structured diagnostic interview and parent and teacher ratings. Both (a) higher levels of inattention and (b) ADHD diagnosis were associated with poorer inhibitory control of irrelevant information during lexical ambiguity resolution (e.g., $r=.26$, $p<.05$), as well as with decreased ability to revise or suppress misinterpretations after syntactic garden paths (e.g., $r=.32$, $p<.01$). Girls with

ADHD were more impaired than boys (interaction: $p<.01$). For children with RD, lower-order language problems (e.g., word decoding, understanding complex syntax) affected higher-order inhibitory processes during language comprehension, yielding findings similar to those found in children with ADHD. Taken together, the pattern of results suggested that ADHD and RD do share deficits in inhibitory mechanisms that protect higher-order language comprehension, but that these may develop via different pathways. In ADHD, these impairments may develop directly from core cognitive inhibition deficits, whereas in RD they may arise secondarily to language automatization failures and subsequent requirements for more effortful processing of language (which leaves fewer resources for inhibition in higher-level language tasks). This was the first study to use these tasks to assess inhibitory mechanisms in language comprehension in ADHD. Identification of these difficulties may help clarify the role of language in the self-regulatory and executive functioning problems that characterize the disorder. Implications for understanding the etiology of the high co-occurrence of ADHD and RD are discussed.

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Inhibitory Language Deficits in Attention Deficit/Hyperactivity Disorder and Reading Disorder: A Candidate Shared Deficit

Attention deficit-hyperactivity disorder (ADHD) and Reading Disorder (RD) are among the two most commonly diagnosed psychological disorders of childhood. ADHD affects some 3-5 percent of school-aged children while RD affects approximately 3-9 percent (Offord et al., 1987; Shaywitz, Shaywitz, Fletcher, & Escobar, 1990; Rutter, 1978). Both disorders can be highly impairing and often lead to school failure, low self-esteem, oppositional behavior, and other emotional or psychological problems (Frank, 1996). Considerable empirical evidence supports the existence of distinct cognitive and neuropsychological deficits in the two disorders, with the most robust of these being the double dissociation between (a) phonological processing deficits in RD and (b) executive function deficits in ADHD (Pennington, Groisser, & Welsh, 1993). Findings of distinct deficits do not, however, explain a puzzling characteristic of the two disorders—the high frequency with which they co-occur (Beitchman, Hood, & Inglis, 1990). Based on their prevalences, the expected rate of ADHD+RD comorbidity in the community would be approximately 1 percent if they are causally unrelated, even assuming upper bound estimates. Yet, studies consistently find a 10 to 90 % incidence of comorbidity between the disorders, with conservative estimates putting the overlap at 30-50% depending on the sample examined (Beitchman & Young, 1997; Hinshaw, 1992).

One logical explanation for this high overlap might be that RD children develop behavioral problems resulting from school frustration, whereas ADHD children fail to achieve due to inattention in school. Empirical evidence to date suggests, however, that at best, this "phenocopy" explanation accounts for only some of the cases of ADHD+RD co-occurrence (Spreen, 1989). One potential alternative explanation is that the risk for developing both disorders increases as a result of an as yet unidentified shared cognitive deficit. The interface between language processing and inhibitory control is one theoretically promising but largely unexplored possibility for such a shared deficit. Language and inhibitory processes have been examined separately in both ADHD and in RD, but few studies have examined their interaction. Indeed, mechanisms by which irrelevant information is suppressed are one of the leading contenders for a "core deficit" in ADHD, yet are largely unstudied in the language domain—the domain in which one would expect a link to RD to occur.

The current study sought to examine inhibitory-reliant language processes in children with ADHD and with RD, with the aim of exploring whether the disorders share a common cognitive deficit that could help explain their high rates of co-occurrence. Information on a number of topics relevant to the two disorders is provided here so as to establish a framework within which readers can fit the current study. Background regarding diagnostic criteria, symptomatology, and limitations inherent to the DSM-IV (American Psychiatric Association, 1994) classification of ADHD and RD will be reviewed, followed by a consideration of theories regarding the etiology of ADHD+RD comorbidity, evidence that the two disorders have distinct cognitive deficits, and candidate domains for locating a shared deficit. Finally, discussion of the role of inhibition in language processing will be provided in the context of its relevance to ADHD+RD comorbidity as well as its importance to a deeper understanding of ADHD per se.

Background on ADHD and RD

Background on ADHD

ADHD is among the most common reasons for referral to pediatric clinics and other mental health professionals (Offord et al., 1997). The DSM-IV (American Psychiatric Association, 1994) describes ADHD as developing in very early childhood and occurring four to nine times more often in males. As currently defined, the syndrome is diagnosed in the presence of six behavioral symptoms of either hyperactivity/ impulsivity or inattention/disorganization that are extreme for age and begin prior to age seven. Impairment from these symptoms must be present in at least two settings for a period of at least six months. Three sub-types are defined: predominantly inattentive, predominantly hyperactive-impulsive, and combined types. Symptoms such as excessive motor activity often manifest themselves from toddlerhood and usually remain stable and severe throughout childhood. Children with ADHD often experience impaired academic achievement, peer rejection, and difficult family relationships (Barkley, 1996). Although many sufferers experience a waning of hyperactive/impulsive symptoms in late adolescence and adulthood, many others experience poor long-term outcomes such as antisocial behavior and substance abuse, traffic and other accidents, employment problems, and marital problems (Carroll & Rounsaville, 1993; Loeber & Keenan, 1994).

Although the DSM-IV's (American Psychiatric Association, 1994) differentiation of the ADHD syndrome into three subtypes has produced enhanced diagnostic specificity, considerable within-group symptom heterogeneity continues to pose problems for establishing the disorder's construct validity. For example, the majority of children with ADHD—68 percent according to one survey (Offord et al, 1987)—

receives one or more additional, or comorbid, diagnoses (Jensen, Martin, & Cantwell, 1997). Commonly co-occurring disorders include other disruptive behavior disorders (e.g., Oppositional Defiant and Conduct Disorder), anxiety, depression, and learning disabilities (Biederman, Newcorn, & Sprich, 1991; Jensen, Martin, & Cantwell, 1997; Faraone et al., 1993; Nottleman & Jensen, 1995; Hinshaw, 1992). Reading disorder is a particularly important yet poorly understood comorbid condition as noted earlier.

Background on Reading Disorder

Reading disorder, as currently defined, is diagnosed in the presence of a significant discrepancy (usually defined as 1.5 standard deviations) between normal intellectual abilities and below average reading achievement. Effects can persist into adolescence and adulthood and have a negative impact on interpersonal relationships, earning power, and school or professional achievement (Culbertson & Edmonds, 1996; Aram, Ekelman, & Nation, 1984). As is the case for ADHD, the current diagnosis of RD suffers from a number of problems with its construct validity. The DSM-IV and empirical literature differentiate between RD and "garden-variety" poor reading, which is characterized by below average functioning in both reading achievement and IQ. Some recent empirical evidence disputes this distinction, however, finding no differences between the two groups' reading impairments (Beitchman & Young, 1997; Shaywitz, Fletcher, & Shaywitz, 1994). In addition, after extensive work in a variety of cognitive domains (including visual processing deficits and "surface" dyslexia), a growing consensus in the empirical literature favors phonological processing impairments as central to most manifestations of RD (Morris et al., 1998; Pennington, 1991). Yet, this impairment is not incorporated into current diagnostic criteria.

Children with RD are also a heterogeneous group. One recent study, for instance, identified *seven* different subtypes of RD. Although most of these subtypes shared a phonological processing deficit, they differed according to deficits in verbal short-term memory, processing speed, and rapid serial naming (Morris et al., 1998). Children with RD also commonly experience psychiatric problems. ADHD is the most common of these, with reported rates of co-occurrence between 15 and 53 percent in both clinical and community samples (Baker & Cantwell, 1987; Cantwell & Baker, 1991; Riccio & Hynd, 1993; Beitchman, Hood, & Inglis, 1990; Prizant, Audet, Burke, Hummel, Maher, & Theadore, 1990; Wood & Felton, 1994; Shaywitz, Fletcher, & Shaywitz, 1994).

Conceptual Diagnostic Issues

Ultimately, characterizing groups according to cognitive or neuropsychological deficit patterns, if it can be done, could set the stage for uncovering neurobiological or other etiologies and, in turn, for developing more effective preventions or treatments (Shaywitz, Fletcher, & Shaywitz, 1994). Such information would, at the same time, help determine whether the separation of ADHD from key comorbid disorders in the DSM-IV's behaviorally-based taxonomy is valid from the point of view of associated neuropsychological deficits. Yet, doing so is not straightforward.

Due to the considerable heterogeneity within ADHD and RD samples, distinguishing these disorders' primary causes from their secondary symptoms is difficult. The usual practice of studying DSM-IV or other behaviorally-defined clinical groups underscores this heterogeneity problem, in that a diagnosed group may well consist of children with similar behavioral symptoms but different neurobiological etiologies. From a neuropsychological perspective, then, DSM-IV diagnostic categorization may sometimes lump distinct cognitive dysfunctions into a single diagnosis or, alternatively, differentiate related dysfunctions into separate diagnoses. In its tacit adoption of a descriptive medical syndrome model, the DSM-IV also admittedly fails to address developmental or causal pathways to disorder. For instance, the same symptoms and diagnostic criteria (i.e., number of symptoms) are required for diagnosis regardless of age.

These issues are especially salient to questions regarding the causes of comorbidity. For instance, comorbidity between ADHD and RD could result from: (1) a distinct syndrome with a unique etiology (e.g., ADHD+RD has a unique etiology compared to ADHD or RD alone; Rowe & Rowe, 1992), (2) the independent or chance co-occurrence of multiple disorders (unlikely in ADHD+RD as noted earlier), or (3) a single shared underlying neuropsychological deficit that produces vulnerability towards different manifestations of disorder (i.e., different phenotypes), and leads to greater than expected co-morbid cases (Willcutt et al., 2001). Because DSM-IV classification is based solely on a behavioral level of analysis, attempting to differentiate syndrome-specific from generalized or shared cognitive deficits (i.e., deficits common to both disorders) may be a key strategy for clarifying the etiological relationship between ADHD and RD.

Despite the DSM-IV's limitations, the validity of its diagnoses (and the symptom clusters upon which they are based) is extensively supported empirically and provides a common framework for describing and classifying children across studies (Lahey et al., 1994). Furthermore, although there is considerable heterogeneity among individuals with ADHD or RD diagnoses, the use of these classifications has yielded well-replicated group-specific cognitive and neurological deficits, notably executive function deficits in

ADHD and phonological processing deficits in RD. Thus, DSM-IV categorization provides an essential tool for categorizing and describing psychological problems both for clinical and empirical purposes.

Summary

Despite the benefits of the DSM-IV (e.g., its wide-spread use across studies and empirically validated symptom clusters), it does not shed light on etiology, so improved understanding of the cognitive and neuropsychological deficits associated with ADHD and RD may be one useful approach for clarifying the relationship between the two disorders.

ADHD+RD Comorbidity Findings

A note on terminology

Before reviewing key aspects of RD and ADHD comorbidity, a note about some of the distinctions in this literature is necessary. The empirical literature on the co-occurrence of ADHD and language or learning problems varies widely according to how the impairments are classified and which specific problem is being studied. Studies on the relationship of ADHD to RD, learning disability (a broader category which subsumes RD), or language impairments (an overlapping but also broad category) could reasonably be discussed as distinct bodies of literature. Broad language impairment, for instance, is a sufficient although not a necessary condition for producing a reading deficit. However, though they are distinct concepts, RD, learning disability, and language impairments are also highly inter-related. RD, for instance, is often preceded by language impairment and is the most common learning disability associated with language impairment (Riccio & Hynd, 1993; Riccio & Jemison, 1998). Moreover, language impairments and learning disabilities are often distinguishable primarily by the age of the child, with language impairments during preschool more likely to be manifested as learning disabilities at school-age (Kahmi & Catts, 1986).

A second reason for including findings regarding learning disability and language impairment is the current study's emphasis on language functioning as the possible shared mechanism in RD and ADHD. Language impairments can act as a mediator between attention and reading problems (Riccio & Jemison, 1998) and, conversely, RD may mediate links between language impairment and disruptive behavior problems during development (Tomblin, Zhang, Buckwalter, & Catts, 2000). Language impairment therefore may play a crucial role in understanding the relationship between RD and ADHD.

Thus, my review of findings on ADHD+RD includes studies of learning disability (LD) or language impairments (LI). Whenever possible, or relevant, the specific syndrome under study will be identified and distinctions noted.

Background on ADHD+RD Comorbidity

Depending on the criteria used, on average, ADHD children have comorbidity rates of between 30 to 50 % for formal learning disorders (Tomblin et al., 2000; Semrud-Clikeman et al., 1992; Hinshaw, 1992). A number of explanations exist for the wide discrepancies in comorbidity estimates between studies. These include sampling biases (e.g., use of clinical versus community samples or RD clinic-recruited versus ADHD clinic- recruited samples) and the criteria used to diagnose RD (e.g., IQ-achievement discrepancies, diagnosis by achievement deficits without comparisons to IQ, or exceeding cut-offs on any one of several different diagnostic measures; Semrud-Clikeman et al., 1992). Thus, studies have reported academic difficulties or LD diagnoses in a large percentage of ADHD children, with one study finding over one-half in need of tutoring and one-third placed in special classes or repeating a grade (Faraone et al., 1993; Cantwell & Baker, 1991; Hinshaw, 1992; Love & Thompson, 1988; Carlson, Lahey, & Neeper, 1986; Barkley, DuPaul, & McMurray, 1990; Lamminmaki, Ahonen, Nirhi, Lyytinen, & deBarra, 1995; Trautman, Giddan, & Jurs, 1990; Elbert, 1993).

With regards to children with RD, more subclinical symptoms of ADHD are exhibited compared to nonimpaired children (Willcutt et al., 2001). Voeller (1999) concluded that the occurrence of attention problems in RD may be much higher when examined from a dimensional rather than a categorical perspective (i.e., allowing "sub-diagnostic" but impairing symptoms to be noted) and when classification is based on neurological/cognitive tasks rather than behavioral ratings. Voeller argued that most RD children have some degree of cognitively-measurable attentional deficit.

Some evidence suggests that learning and language problems in ADHD may vary according to subtype—specifically, that they may be more common in the inattentive subtype (Tirosh & Cohen, 1998; Lamminmaki, Ahonen, Narhi, Lyytinen, & deBarra, 1995; August & Garfinkel, 1989; Shaywitz, Fletcher, & Shaywitz, 1994). August and Garfinkel (1989) differentiated between a behavioral and cognitive subtype of ADHD and found the cognitive subtype to be associated with inattention, linguistic information processing deficits, and academic underachievement. One study in Chile also found reading problems to be more prevalent in inattentive than in combined type children, though combined-type children also demonstrated more reading problems than control children (Lamminmaki et al., 1995). Thus, language and learning problems are found in both subtypes of ADHD children.

In addition to subtype differences, learning disabilities and language impairment in ADHD children increase with age (or underlying learning disabilities or language impairments can be more easily identified as academic demands increase in later school grades; Tirosh & Cohen, 1998). For instance, a combination of hyperactivity, inattention, and language delay during preschool may be a marker for later diagnosis with ADHD (Beitchman, Tuckett, & Batth, 1987; McGee, Partridge, Williams, & Silva, 1991). A longitudinal study on Israeli school children found that 80 percent of preschoolers with this triad of symptoms had a diagnosis of combined or inattentive subtypes of ADHD when followed-up between 7 and 14 years of age (Ornoy, Uriel, & Tennenbaum, 1993). Furthermore, Baker and Cantwell (1992) reported that, wheareas 20 percent of 6 and 7 year-olds with ADHD + history of speech/language disorder were also diagnosed with a learning disability, this rate increased to 86 percent of children aged 11-15 (Baker & Cantwell, 1992).

Sex of a child is also an important factor in the incidence of comorbidity between ADHD and RD. Although ADHD and RD are both more common in boys than girls, Beitchman, Hood, and Inglis (1990) reported that girls with speech/language disorders were twice as likely as boys to have a co-occurring psychiatric disorder. Girls are therefore more highly represented in groups of children with concurrent ADHD and language disorders than in samples of ADHD-only children (Berry, Shaywitz, & Shaywitz, 1985; Love & Thompson, 1988; Tirsoh & Cohen, 1998). This difference may be especially true of girls in the predominantly inattentive subtype (Love & Thompson, 1988). Girls with concurrent ADHD and language impairments also demonstrate more severe language deficits, lower verbal IQ's, and poorer academic performance than ADHD boys with language impairments (Berry, Shaywitz, & Shaywitz, 1985; Beitchman, Hood, & Inglis, 1990). These sex differences may be an artifact of ascertainment biases (i.e., only severely impaired girls are referred for treatment due to demonstration of fewer behavior problems), or may be due to polygenetic transmission factors (i.e., girls must carry a higher genetic load and meet a higher threshold before phenotypic impairment becomes evident) (Berry, Shaywitz, & Shaywitz, 1985). In either event, consideration of possible sex differences is important in studies of ADHD+RD comorbidity.

Now that a summary of overarching background issues relevant to understanding ADHD+RD comorbidity has been provided, I next examine findings on the cognitive and neuropsychological deficits associated with comorbid ADHD+RD. Findings in this domain will lay a foundation upon which to describe candidates for shared deficits that potentially could explain this comorbidity, enabling description of the rationale for the current study. Most comorbidity studies to date have focused on determining whether the cognitive and neuropsychological deficits associated with each disorder co-occur in their comorbid form or whether one of the disorders is a phenocopy. Evidence for each of these will now be reviewed.

Cognitive and Neuropsychological Findings on ADHD+RD Comorbidity

Phenocopy Findings.

A number of studies have supported the idea that comorbid ADHD+RD has only *one* disorder's neuropsychological impairments (e.g., phonological processing *or* executive functioning deficits), while the symptoms of the other disorder behaviorally mimic, or are phenocopy symptoms, of true neuropsychological deficits (e.g., hyperactivity only as a sequelae of RD-related school frustration; poor reading achievement as a sequelae of ADHD-related inattention at school; Zentall, 1993; Cantwell & Baker, 1991; Pennington, Groisser, & Welsh, 1993; Frith, 1995). Some empirical findings suggest that comorbid ADHD+RD involves RD-specific cognitive deficits (McGee, Williams, Moffitt, & Anderson, 1989), while ADHD symptoms result from school frustration and other negative effects of early reading difficulties (Tomblin et al., 2000; McGee & Share, 1988; Stanovich, 1986). A study by Shaywitz and colleagues (1995), for example, reported significant impairment in ADHD+RD children on measures of phonological processing and teacher ratings of activity, attention, and behavior, but *not* on a cognitive measure of visual attention (an ADHD-related deficit measured by an underlining task). Similar findings of phonological but not executive function deficits in an ADHD+RD group were reported by Pennington, Groisser, and Welsh (1993). Results of these studies therefore suggest that comorbid ADHD+RD consists of RD children with secondary behavior problems mimicking ADHD.

However, other studies have found the cognitive deficits of ADHD to be primary in the comorbid group, whereas symptoms of RD are secondary results of school failure (i.e., no problems with phonological processing are found). Rowe and Rowe (1992), for example, reported a reciprocal relationship between primary inattention in school and subsequent poor reading achievement that then leads to further exacerbation of inattentiveness in school. Fergusson and Horwood (1992) found that attention influenced reading achievement even though reading achievement did not influence attention.

These studies suggest that ADHD+RD is not "truly" comorbid (i.e., only one disorder has the underlying cognitive deficit of the pure disorders). Although this finding is probably supported in some cases of ADHD+RD comorbidity, the majority of recent research has not supported the phenocopy hypothesis, instead finding that the comorbid group has distinct cognitive deficits associated with both pure disorders. These findings will now be reviewed.

Distinct Deficits Findings

Some studies examining ADHD+RD comorbidity have found that neuropsychological deficits characteristic of both "pure" disorders co-occur in the comorbid form. Tirosh et al. (1998), for example, found that parent and teacher behavioral report of attention and learning problems both loaded on the same factor in ADHD+LD children. Several studies have reported a double dissociation between ADHD and RD on measures of executive functioning (ADHD) and phonological processing (RD) (Pennington, Groisser, & Welsh, 1993; Shaywitz, Fletcher, & Shaywitz, 1995, Nigg, Hinshaw, Carte, & Treuting,1998; Ackerman, Dykman, & Gardner, 1990; Reader, Harris, Schuerholz, & Denckla, 1994; Willcutt et al., 2001; Klorman et al., 1999). In addition, ADHD-specific deficits in effortful executive control processes and RD-specific deficits on more automatic processes have also been documented (Carte, Nigg, & Hinshaw, 1996; Kemp & Kirk, 1993; Ackerman, Anhalt, Holcomb, & Dykman, 1986; Ackerman, Anhalt, Dykman, & Holcomb, 1986). Certain language deficits also appear to be specific to diagnosed language impairments or learning disabilities, regardless of comorbid disorders (Vallance, Im, & Cohen, 1999). Cohen et al. (2000), for instance, reported that receptive and expressive language deficits were specific to diagnosed language impairment and were not impaired in children with "pure" ADHD relative to those with other comorbid psychiatric diagnoses, thus suggesting that any language deficits in ADHD resulted from co-occurring language impairment.

Severity Findings

Other findings have suggested that the comorbid ADHD+RD group not only has the cognitive symptoms of both disorders, but is also more globally impaired than those with the pure forms of the disorders. For instance, auditory memory (Kataria, Hall, Wong & Keys, 1992; Tarnowski, Prinz, & Nay, 1986) and working memory (Shaywitz et al., 1995; Willcutt et al., 2001) are more impaired in children with ADHD plus language impairments than in either ADHD-only or RD-only children. ADHD plus language impaired children have also been found to be more distracted by external stimuli than either pure ADHD or language impaired children (Cotugno, 1987) and to have greater impairment in word decoding and sequential memory (August & Garfinkel, 1989).

Final Methodological Note

Several methodological inconsistencies in studies of ADHD+RD comorbidity make it difficult to generalize findings about the co-occurrence of the disorders. For instance, few studies (with several notable exceptions: e.g., Pennington, Grossier, and Welsh, 1993; Purvis & Tannock, 1995) have simultaneously utilized a sample including children with the "pure" form of both disorders as well as children with their comorbid form. Thus, the majority of studies have used samples of children with *either* RD *or* ADHD and compared them to those with ADHD+RD (e.g., Halperin, Gittelman, Klein, & Rudel, 1984). They also tend to study functioning in only one domain (e.g., language *or* executive function). Sampling biases are an additional concern in many of these studies, since the comorbid children were often drawn from primarily RD or primarily ADHD samples (e.g., children from ADHD or RD clinics rather than from community samples). Finally, the criteria used to define RD or language impairment have varied widely across studies. Some studies, for instance, required larger IQ-achievement discrepancies than others did, while other studies required poor achievement without any consideration of discrepancy from IQ (Semrud-Clikeman et al., 1992; Purvis & Tannock, 2000).

Conclusions

Despite these methodological problems, findings provide considerable evidence for the co-occurrence in ADHD+RD of cognitive deficits characteristic of the respective "pure" disorders. Though successful in describing the cognitive and neuropsychological impairments in ADHD+RD, research has not advanced nearly as well the question of *why* these two disorders co-occur so frequently. One potential answer is that, in addition to their *unique* cognitive dysfunction, both disorders also *share* another cognitive or neuropsychological deficit (such as inattention, disinhibition, or working memory impairment) that may predispose an individual to development of both disorders and which may lead to greater than chance co-occurrence (Love & Thompson, 1988; DeLong, 1995; Purvis and Tannock, 1999; Willcutt et al., 2001; Spreen, 1989; Denckla, 1996). This hypothesis of a shared deficit, though not well-explored, provides an intriguing possibility for explaining the etiology of ADHD+RD comorbidity. If this shared deficit theory is true, then both pure disorders should have a common deficit. Attention to the existence of possible shared cognitive deficits in each of the "pure" forms of the disorders (RD alone, ADHD alone) may thus provide clues regarding the etiological underpinnings of ADHD+RD comorbidity.

Evidence for this hypothesis will now be considered. In each section, findings of studies that directly compared ADHD and RD will be reported first, followed by findings for each disorder individually. Because the shared deficit hypothesis is not yet well-explored, most empirical findings are from studies examining one of the "pure" disorders. Again, because of methodological disparities across studies, this review includes findings for LD and language impaired children, in addition to those for RD.

Empirical Evidence for Shared Deficits

Genetics Studies

Genetic studies have provided mixed evidence regarding the etiology of ADHD and RD. Faraone and colleagues (1993) reported evidence for independent genetic precursors of the two disorders (perhaps through nonrandom mating). In a twin sample selected for ADHD, children with ADHD + LD (learning disability) had a greater number of relatives with a learning disability compared to ADHD-only children and an equal proportion of relatives with ADHD. However, other studies have supported a shared etiology for the two disorders. In a sample of twins selected for the presence of RD, 45 percent of the proband deficit in reading was accounted for by genetic factors that also contributed to hyperactivity. Due to the significant bivariate heritability between ADHD and RD, common genetic influences were concluded to contribute to the co-occurrence of the two disorders, even if nonrandom (cross-assortative) mating was also a contributing factor (Light, Pennington, Gilger & DeFries, 1995; Willcutt et al., 2001).

Anderson (1999) reported results of studies in rodents that provide one preliminary theory regarding the genetics of ADHD+RD co-occurrence. These studies examined the effects of mutations involving the Dlx-1 and Dlx-2 genes, which derive from the subventricular zone of the lateral geniculate eminence and play a role in cell migration and differentiation in the striatum and lateral forebrain. Mutations of the genes caused a proliferation of cells in the striatum that never migrated to neocortex. In particular, a 75 percent reduction in GABAergic interneurons of the neocortex occurred in those rodents with a Dlx-1 or Dlx-2 mutation. Given hypothesized inhibitory deficits (often related to functioning of GABAergic neurons) and striatal involvement in ADHD (discussed below) as well as some evidence linking RD with alterations in the lateral geniculate nucleus and its magnocellular pathways, these findings provide one theoretical mechanism of genetic transmission.

Neuroimaging

Imaging studies have also provided evidence for shared deficits. Hynd et al. (1990) found several shared neuroanatomical differences in ADHD and RD individuals versus controls. For instance, both ADHD and RD groups demonstrated smaller MRI-measured widths of right anterior brain regions compared to control subjects. RD subjects also exhibited a significantly shorter insular region bilaterally, while those with ADHD fell between RD and control subjects, but were nonsignificantly different from both groups (Hynd et al., 1990). A RD-related right>left planum temporale length was the main distinguishing characteristic differentiating ADHD and RD individuals (Hynd, Semrud-Clikeman, Lorys, Novey, Eliopulos, & Lyytinen, 1990).

This pattern of partially overlapping neural abnormality also extends to findings involving striatal activation. Although decreased striatal activation has previously been associated with ADHD (Lou, Henriksen, Bruhn, Børner & Nielsen, 1989), a recent study suggests this trait may not be specific to the disorder. Lou, Andresen, Steinberg, McLaughlin, and Friberg (1998) studied the relationship between verbal awareness and striatal functioning in a group of ADHD and comparison children using functional imaging to measure regional cerebral blood flow (rCBF). As in previous studies, ADHD children exhibited decreased rCBF in the right striatum compared to controls in semantic processing conditions. Findings also indicated that striatal and infero-frontal activation were related to the language demands of the experimental tasks (semantic processing under passive listening to a series of animal names) for both groups, while activation of the anterior cingulate resulted from higher-order attentional demands (detection of "dangerous animal" targets). Lou and colleagues concluded that the activation of inferofrontal and striatal regions supports their role in verbal awareness. Given that striatal activation is associated with passive language processing and children with ADHD demonstrate decreased striatal activation under these conditions, these findings provide a possible association between ADHD-related brain impairments and deficits in language processing.

Wood and Flowers (1999) conducted a factor analysis of PET activation findings to examine covariation in neuroanatomical regions of interest. They identified nine neuroanatomical factors and compared activation in these factors to behavioral measures of reading and attention. Three distinct phenotypes based on deficits (cut scores identifying 15 percent of population) in phonemic awareness, phonological decoding, and single word reading were created. The phenotypes were related to activation in inferior temporo-occipital, right central-frontal, and thalamic areas, respectively. Interestingly, both phonemic awareness and inattention were related to activation on the bilingual/hippocampal (inferior temporo-occipital) factor, suggesting a possible common substrate to ADHD and RD deficits (or at least for inattention found in those with RD). The relationship between phonological decoding and right hemisphere activation was hypothesized to be related to requirements for integration and synthesis of phonemes. With regards to findings for other symptoms related to ADHD, hypoactivation of bifrontal and biorbital factors was related to impulsivity and D-prime (i.e., discriminating targets from non-targets) on a continuous performance test. The authors also speculated that the findings for inattention, perhaps as found in predominantly inattentive ADHD, may be associated with a more posterior, sensory-perceptual deficit.

Conclusions about Genetic and Neuroimaging Findings

Overall, neuroimaging and genetics data provide fairly strong support for some shared biological correlates in ADHD and RD, particularly shared genetic influences and shared neural abnormalities in right frontal, inferior temporo-occipital, and possibly striatal regions. Some findings in the cognitive literature also provide support for a relationship between the disorders. Auditory processing, working memory, language, and inhibitory processing are all candidate domains that may provide specification for a putative cognitive overlap between ADHD and RD. Evidence for each candidate cognitive domain will now be discussed.

Neurocognitive Deficits

Auditory Processing

Impairments in auditory processing mechanisms provide one potential common pathway of comorbidity in ADHD and RD. Riccio and colleagues (1994) reported that differences in behavioral symptom profiles between ADHD children with and without language impairments disappeared when central auditory processing was used as the measure of language impairment classification. Thus, the behavioral correlates of central auditory processing disorder and ADHD appeared to be similar. Children with ADHD have also been found to demonstrate reduced N40 evoked potential amplitudes similar to non-impaired younger children. Dysfunction (or immaturity) in the brainstem thalamo-cortical projections underlying the lowest level of the auditory system (which controls sound localization, noise suppression, and signal detection/target selection) are hypothesized to underlie this dysfunction (McPherson & Davies, 1995). Inhibitory mechanisms (which will be discussed in greater detail later) may influence this thalamo-cortical processing mechanism, thereby suggesting a potential cause of auditory processing problems in ADHD.

Auditory attention and auditory processing have also been found to improve in children with ADHD following Ritalin administration. This improvement was demonstrated by better performance on hit rate and false alarms for an auditory continuous performance test and on a receptive language test requiring following increasingly lengthy and complex commands (Token Test). ADHD children did not show improvement on an auditory figure-ground test that measured ability to discriminate words in the presence of competing background noise, suggesting the possibility of a more severe deficit or a deficit in a pathway not sensitive to Ritalin treatment (Keith & Engineer, 1991).

Interestingly in light of the ADHD findings, auditory deficits in children with RD are also supported. On an auditory continuous performance task comparing responses to rhymed words versus the lowest volume tone in a group, children with RD demonstrated anterior temporal activation on both tasks in contrast to the temporoparietal and posterior frontal activation pattern of control children (Rumsey et al., 1992). Children with RD also demonstrated increased metabolism in the medial temporal lobes bilaterally compared to controls on an auditory continuous performance task that required response to a target syllable (Hagman, Wood, Buchsbaum, Tallal, Flowers, & Katz, 1992). Examination of ERP activation during a tone discrimination task revealed an absence of the right hemisphere lateralized activation pattern of control subjects, as well as impaired ability to discriminate deviant tone patterns. No differences were found for discrimination of pairs of tones (i.e., those without patterns). These deficits were interpreted to support a basic nonlinguistic auditory processing deficit that occurs under requirements for discrimination of temporal patterns within the context of other sounds (e.g., like phonemes in words) (Kujala, Myllyviita, Tervaniemi, Alho, Kallio, Naatanen, 2000).

Summary. Overall, then, evidence supports the existence of auditory processing deficits in both ADHD and in RD. Few, if any studies, appear to have directly compared the deficits of the two groups or their comorbid form, however. Although auditory processing is thus a viable candidate for a shared deficit in the two disorders, this deficit could also occur subsequent to another, more primary, shared impairment such as in inhibition (as suggested above by McPherson & Davies, 1995).

Working Memory

Working memory—itself a multi-component construct-- is one of the most widely studied domains of evidence for common deficits in ADHD and RD. Both ADHD and RD children demonstrate deficits on verbal and spatial span tasks (Shaywitz, et al., 1995, Siegel & Ryan, 1987; Cohen et al., 2000), on linguistic and semantic fluency tasks (Felton, Wood, Brown, Campbell & Harter, 1987), and on confrontation and rapid automatized naming tasks (Ackerman, Anhalt, Holcomb, & Dykman, 1986; Tannock, Marinussen, & Frijters, 2000). However, results have varied considerably across studies. For instance, verbal and nonverbal working memory and rapid naming impairments are more often associated with RD (Siegal & Ryan, 1989; Cohen et al., 2000; Tirosh & Cohen, 1998; Felton et al., 1987; August & Garfinkel, 1990, Nigg et al., 1998), and are typically more severe than in ADHD -- especially for RD+ADHD (Shaywitz et al., 1995; Willcutt et al., 2001; Cohen et al., 2000).

Age and type of task may provide some explanations for discrepant results across studies. Deficits in children with ADHD and children with RD, for example, often begin to appear as both task demands and requirements for controlled processing increase when they begin elementary school. In addition, younger ADHD children are more likely to demonstrate working memory impairments (Mariani & Barkley, 1997; Siegal & Ryan, 1989). Delayed development of the mechanisms underlying working memory (perhaps in inhibition of competing information, which will be discussed later) could account for these age-related differences. Given the possibility for development delays, consideration of age is important in the study of ADHD+RD phenomenology.

Relationship to phonological processing and reading. In addition to the direct findings that support working memory deficits in both ADHD and RD children, some research supports a connection between working memory and phonological processing abilities. ADHD children's performance on phonological processing tasks becomes impaired as the working memory demands of the task increase. Thus, whereas ADHD children do not show impairment in nonword decoding, their performance on phoneme segmentation and deletion tasks-- while not as impaired as in children with RD-- is deficient versus control children in some studies, although not yet widely replicated (Purvis & Tannock, 2000; Willcutt et al., 2001). Furthermore, Mariani and Barkley (1997) found that preschool children with ADHD demonstrated deficient word reading/decoding ability on a simple word-recognition task that loaded strongly on a working memory factor. The authors proposed that early word recognition abilities may depend on working memory in children with ADHD rather than phonological processing factors. Working memory deficits in ADHD children might then serve as an early cognitive vulnerability for development of RD.

Research in nonclinical groups has also shown that individual differences in working memory predict reading ability (Daneman & Carpenter, 1980; Daneman & Carpenter, 1983). Text comprehension can be predicted by a text's working memory demands (Britton & Gulgoz, 1991) as well as an individual's working memory capacity (Lorch & van den Broek, 1997). Cantor and Engle (1993) hypothesized that working memory constraints rather than problems with lower-order linguistic processes accounted for impaired inferential abilities in less skilled readers. In one study, adults with low working memory spans were unable to incorporate probabilistic information to resolve syntactic ambiguities while reading, despite adequate knowledge of that information (Pearlmutter & MacDonald, 1995). As discussed later, such language tasks may be potentially useful in examining ADHD and RD.

Summary. Considerable evidence therefore supports the existence of working memory impairments in both ADHD and in RD, as well as a possible connection between working memory and phonological processing/reading ability. Examination of language impairments in the two disorders will provide further information regarding mechanisms by which ADHD and RD may interact.

Language

Language deficits are a central component of RD. In addition to phonological processing deficits, RD children demonstrate deficits in syntactic, semantic, and pragmatic aspects of language processing (Purvis & Tannock, 1997; Tannock & Schachar, 1996; Bender, 1996; Cohen, Vallance et al., 2000). Some RD-specific deficits have included problems with referential cohesion (understanding and utilization of pronouns, possessive adjectives, demonstratives, and comparatives), over-use of ambiguous references in oral narratives (Roth, Spekman, & Fye, 1995; Purvis & Tannock, 1997), and giving less task-relevant information to a listener under instructional conditions (Spekman, 1981). Relative to children with ADHD, children with RD demonstrate problems with semantic/receptive language and story recall that occur despite application of effortful learning strategies (which are not used by children with ADHD) (Purvis & Tannock, 1997; Tannock and Schachar, 1996; O'Neil & Douglas, 1991). Syntactic morphology and complex language deficits have also been reported to be unique to RD (Javorsky, 1996). However, at least one other study has found syntactic difficulties in ADHD children as well (Cohen, Davine, Horodezky, Lipsett, & Issacson, 1992).

Language deficits in children with ADHD that are independent of comorbid learning disability status have also been documented. Findings typically support deficits in the pragmatics of language, but not in the receptive/expressive domains of language, which include phonological, syntactical, and semantic subsystems. Compared to children with RD, for example, children with ADHD exhibit more externalized and less internalized self-talk and less effective use of language to control their behavior (Berk & Landau, 1993; Berk and Potts, 1991). List-learning and list-recall impairments are also ADHD-specific, suggesting the appearance of deficits when organizational requirements increase (Felton et al., 1987; Chang et al., 1999). ADHD children have also been found to have problems adjusting language to the listener and for specific social or communicative contexts (Laundau & Milich, 1988; Whalen et al., 1979) and to fail to answer questions or comply with commands during parental interactions (Tarver-Behring, Barkley, & Karlsson, 1985; Barkley, Cunningham, & Karlsson, 1983).

Pragmatics deficits are also pronounced (Humphries, Malone, Koltun, & Roberts, 1994; Cohen et al., 2000; Tannock, Purvis & Schachar, 1993; Tannock and Schachar, 1996). Westby and Cutler (1994) asserted that a number of DSM-IV ADHD symptoms are consistent with pragmatic language deficits. Although these deficits are not evidence of a pragmatic language deficit in and of themselves, symptoms include talking excessively, difficulty awaiting turns, interrupting others, blurting out answers to questions before they are finished being asked, and not listening. Other commonly observed ADHD behaviors, such as switching topics abruptly, speaking unconnected thoughts, and intruding into conversations at awkward moments were also theorized to be consistent with pragmatic language impairment.

Summary. Executive function deficits, specifically in organization and self-monitoring, have been hypothesized to produce the pragmatics language deficits in children with ADHD. This interpretation is consistent with other research in ADHD that has found executive functioning (including in the domains of planning, organization, and motor output) as a major replicated and potentially primary element in the ADHD syndrome (Barkley, 1997). The exact mechanism producing these language-related executive function deficits has not been well explored, however. In addition, little research has examined whether children with ADHD might demonstrate receptive language deficits under increased requirements for executive or inhibitory control. At the same time, there has been little exploration of whether RD-related deficits are related to (or cause) problems in inhibitory functions.

Theories in the cognitive literature provide one possible means by which to understand the relationship among phonological processing, working memory, and executive dysfunction. Baddeley and Hitch (1994) hypothesized that working memory holds words, sentences, numbers, or phrases by means of a "phonological loop" under the control of a "central executive." Denckla (1996) suggested that phonological processing problems in RD lead to dysfunction in the phonological loop and, thus, a failure to provide language to the central executive for the performance of executive functions. In contrast, executive function impairments in ADHD produce an inability to efficiently utilize and organize information from the phonological loop, leading to skill acquisition problems that may affect the processes involved in learning to read. According to this theory, then, executive control and language processes are inextricably linked. The interface between language and executive/inhibitory processes therefore may be a promising place in which to look for a shared deficit in ADHD and RD.

Conclusions about Neurocognitive Deficits

Empirical support for shared deficits in ADHD and RD in the auditory processing, working memory and language domains suggest that there may be some other, primary, shared impairment that produces secondary deficits in these domains. One possibility is that inhibitory mechanisms play a role in the appropriate functioning of working memory, auditory processing, and language and that impairments in such mechanisms can produce secondary deficits in these domains. Recent findings that are suggestive of inhibitory deficits in RD create further intrigue about whether weakness in inhibitory mechanisms that help support language processing may be a potential shared mechanism underlying ADHD and RD comorbidity (Purvis & Tannock, 2000). Examining the role played by inhibition in language processing may be especially helpful for determining whether there is a shared inhibitory deficit in ADHD and RD, because both of these impairments are central to one or the other disorder (i.e., language in RD, inhibition in ADHD). Furthermore, although empirical findings in the cognitive literature support the role of inhibitory mechanisms in language processing, for the most part this idea has been largely unexplored in clinical samples.

In order to fully address the possible connection between ADHD and RD-related inhibitory deficits and language impairments, the empirical literature on inhibitory functioning in ADHD and RD will now be reviewed and will be followed by findings on the relationship between inhibition and language processing. The cognitive literature makes two important distinctions about types of inhibitory mechanisms -- effortful vs. automatic inhibition and behavioral versus cognitive inhibition. These distinctions and their relevance to ADHD and RD will now be reviewed.

Inhibition: New Candidate for a Shared Deficit?

Theoretical Background

Effortful versus Automatic Inhibitory Processes

Following established traditions in the literature, Nigg (2001) defined effortful inhibitory control as the "top down" active suppression of a cognition or behavior in the service of attaining a goal (as internally represented in working memory). Neuroanatomical substrates hypothesized to underlie effortful inhibition include the anterior cingulate as well as dorsolateral- and orbito- prefrontal cortex and associated basal ganglia structures (Casey, 2001; Castellanos et al., 1996). Automatic inhibition has been described as including attentional processes responsible for preconscious selection of information that enters consciousness. Selection of context-appropriate meanings of homographic words is cited as an example of automatic inhibitory control, because it involves suppression of previously activated cognitive contents that occurs without apparent intention or conscious awareness and seems to happen automatically (Harnishfeger, 1995). Inhibition in terms of attentional functioning and working memory is both automatic (suppression of unattended locations) and deliberate (suppression of competing distractors). These inhibitory functions have been well-described in relation to visual-motor processes (Nigg, 2000), but less well described in language processes.

On one hand, inhibitory processes of one kind or another may *distinguish* ADHD and RD. Some theories suggest that children with ADHD are likely to experience failures in cognitive or behavioral processes requiring effortful or deliberate inhibitory control, whereas children with RD demonstrate difficulties with automatic suppression mechanisms (Ackerman, Anholm, Dykman et al., 1986; Ackerman, Anholt, Holcomb et al., 1986). One study, for instance, found deficits on an automaticity/language factor of executive functioning to be associated with RD and deficits on an attention/maintenance factor of executive functioning to be associated with ADHD (Kemp & Kirk, 1993). Furthermore, recent findings suggest that impaired rapid naming of colors (which requires effortful semantic processing) is associated with ADHD, while impaired naming of numbers (which requires more automatic processes) is associated with RD (Tannock, Martinussen & Frijters, 2000; Nigg et al., 1998). Evidence that ADHD (at least the combined type) is related to impairments in frontally-mediated neural mechanisms and RD to temporoparietal neural deficits also supports the idea of effortful versus automatic inhibition deficits as distinguishing the two disorders. The mechanisms underlying the inattentive subtype of ADHD have received less investigation and are less clear. Due to the nature of the attentional impairments exhibited by inattentive subtype children, some evidence has suggested that, similar to RD, the inattentive subtype may involve deficits in parietally-mediated or automatic attentional mechanisms (Schaughency & Hynd, 1989; Goodyear & Hynd, 1992).

Although it may be possible to distinguish ADHD and RD according to impairments in effortful versus automatic inhibitory processes, it is also important to recognize that, just as distinctions between effortful and automatic processes are relative (i.e., on a continuum) rather than absolute, the same may be the case with the inhibitory deficits of children with ADHD and RD. In other words, if children with ADHD and

RD are vulnerable to an inhibitory deficit in language, then their effortful and automatic inhibitory deficits are likely to be on a continuum that is a matter of degree rather than a dichotomous deficit. According to this logic, ADHD and RD children should demonstrate deficits in both automatic and effortful inhibitory processes, although they may experience more *severe* deficits on one or the other end of the continuum (e.g., more severe automatic inhibition deficits in RD and more severe effortful inhibition deficits in ADHD).

Behavioral versus Cognitive Inhibition

Harnishfeger and Bjorkland (1993) defined cognitive inhibition as the suppression of previously activated cognitive contents or processes and resistance to interference from irrelevant information. Cognitive inhibition is responsible for keeping irrelevant information from entering or being maintained in working memory and for preventing disruption of cognitive processes by extraneous information. As just noted, it can be intentional and conscious (i.e., effortful) or unintentional and unavailable to consciousness (i.e., automatic) (Harnishfeger, 1995). Definitions of cognitive inhibitory processes differ somewhat across studies and theories. Gernsbacher (1997), for instance, distinguishes between cognitive *inhibition*, defined as the blocking of activation, and *suppression*, defined as the dampening of existing activation. According to Gernsbacher, interference control requires suppression, but not inhibition. The distinction between suppression and inhibition is not crucial to the present study, so the terms will hereafter be used interchangeably.

In contrast to cognitive inhibition, behavioral inhibition involves the intentional control of behavior, i.e., motor output (Harnishfeger, 1995) and has been associated with size of right prefrontal and basal ganglia structures. Casey (2001) theorized that inhibitory projections of basal ganglia thalamocortical circuits produce inhibition of behavior, whereas excitatory projections from frontal cortex maintain information or representations upon which to act. Orbitofrontal and right anterior cingulate activation has been associated with performance on a response execution (behavioral inhibition) task (Casey, 2001). Cognitive and behavioral inhibition may interact, in that efficient cognitive inhibition can facilitate behavioral control by suppressing inappropriate thoughts or impulses. Because language-related processes like internalized speech (which likely is moderated by a cognitive suppression component) are directly related to self-control, deficiencies in cognitive inhibitory mechanisms that affect language could lead to behavioral regulation problems like those in ADHD.

Inhibitory deficits, especially in relation to motor control or behavioral responses, have been the focus of a number of prominent theories on the etiology of ADHD impairments (Barkley, 1997; Quay, 1997; see Nigg, 2001 for review). Building on the general theories of cortical functioning by Bronowski (1977) and Fuster (1989), Barkley (1997) proposed that the main deficit in ADHD stems from failures in behavioral inhibition. Functionally localized bilaterally to the prefrontal and motor cortex, behavioral inhibition was proposed to create a delay in motor activity for further direction from the executive functions. Failures in behavioral inhibition would then cause executive function failures that are often manifested by difficulties in self-control and goal directed behavior. Barkley proposed that working memory, self-regulation of affect-motivation-arousal, internalization of speech (to be discussed later), and reconstitution rely on behavioral inhibition.

Evidence for deficits in cognitive inhibition in ADHD are less well studied and have mixed support (Nigg, 2001). Casey (2001) found ADHD-related deficits on a stimulus selection task requiring suppression of previously attended stimulus attributes and proposed that these deficits may be associated with impairments in dorsolateral prefrontal cortex.

Development of Cognitive and Behavioral Inhibitory Control

Response inhibition is sufficiently developed by 2nd grade to detect individual differences across children (Harnishfeger & Bjorkland, 1993). Relative delays in development of frontal inhibitory mechanisms in 2nd graders would then cause a child's behavior to be more heavily influenced by prepotent responses than that of non-delayed peers (Dempster, 1993; Barkley, 1997). With regards to development of cognitive inhibition, Dempster (1993) asserted that resistance to interference by both external and internal sources is a major factor in cognitive development and is associated with frontal cortex development. Children may have inefficient inhibitory mechanisms that make them vulnerable to interference by irrelevant information in working memory. As a result, they utilize more mental resources in the service of information processing. As children develop, increased efficiency of inhibitory mechanisms allows them to devote more resources to storage and cognitive strategies (Harnishfeger, 1995; Harnishfeger & Bjorkland, 1993).

Control over interference does not develop uniformly across all domains of processing and can be said to develop from an "outward to inward" direction. For instance, children initially develop the ability to suppress motoric interference, then later perceptual interference, and, finally, develop ability to suppress linguistic interference

(Dempster, 1993). Linguistic interference is greater than motoric interference beginning around 6 years of age (for instance, Stroop interference generally does not occur before age 6), thus making it a key candidate for a shared deficit domain in RD and ADHD—both of which are usually first diagnosed at around age 6. Harnishfeger (1995) reported that inhibitory processes in negative priming do not appear until at least age 8, while ability to ignore irrelevant information doesn't peak until early adolescence.

Harnishfeger and Bjorkland (1993) proposed that children improve information processing capacity and efficiency through the development of direct retrieval mechanisms. These direct retrieval mechanisms are thought to develop by activation of one stimulus and simultaneous inhibition of any other competing stimuli, leading to the eventual development of processes such as direct lexical access. Failure of a stimulus to reach the activation threshold for selection leads to reliance on a piece-meal processing strategy (e.g., phonological decoding rather than direct lexical retrieval). One theory for RD deficits posits delays or failures in the development of skill automatization (Moores & Andrade, 2000). Cognitive inhibition impairments provide one potential explanation for this deficit, in that inability to sufficiently suppress competing "noise" could lead to failures in the development of automatic or direct retrieval mechanisms. Automatization failures (i.e., the continued need for conscious allocation of effort for execution of a routine task) could then create an increased reliance on effortful inhibitory processes for skills that are normally automatic.

Using reading as an example, failure to develop automatic word decoding could increase the processing requirements/effort needed to read a passage, thereby resulting in limited resources available for other cognitive processes, like reading comprehension.

Such resource limitations would also then be likely to produce additional cognitive deficits (Crain & Shankweiler, 1988; Shankweiler et al., 1999). Some support for this assertion is found in the neuroimaging literature. Brunswick, McCrory, Price, Frith, & Frith (1999) reported that college students with RD demonstrated reduced activation in left posterior inferior cortex and increased activation in a pre-motor region of Broca's area while reading pseudowords, despite similar accuracy to non-impaired comparison students. The authors attributed this result to problems with highly automated aspects of reading (specifically, lexical retrieval) and an associated increased need for effortful compensatory strategies.

To summarize, although speculative, if automatic cognitive inhibition deficits cause automatization failures that reduce resources for higher level cognitive processes (i.e., those that typically require greater effort), then performance on tasks that require effortful inhibition will likely also be impaired. Such an explanation could provide a rationale for the co-existence of both automatic and effortful inhibition impairments and, consequently, the co-occurrence of both types of inhibition deficits in ADHD and RD. Importantly, if children with RD have genuine core impairments in automatic inhibition, then they would also be expected to demonstrate problems with nonverbal tasks requiring inhibition. To further explore the role of inhibition in these disorders, discussion now moves to review of empirical findings on inhibitory deficits of various kinds in ADHD and RD. These findings can be broadly classified according to effortful/behavioral inhibition findings and automatic/cognitive inhibition findings. These findings highlight the relevance of studying inhibitory mechanisms as a means of clarifying the relationship between ADHD and RD.

Empirical Findings on Inhibitory Mechanisms in ADHD and RD

Effortful Inhibitory Control and Motor Inhibition

There is considerable empirical support for the existence of an executive-type inhibitory deficit in ADHD that impairs suppression of motor response, though it may or may not be primary (i.e., may be secondary to impairments in arousal, activation, and motivation; see Nigg, 2001 for review). Behavioral inhibition deficits, as measured by Logan's Stop task (Logan & Cowan, 1984), have been demonstrated in a number of studies on children with ADHD. On this task, ADHD children require increased time to stop a prepotent (primed, prepared, or already initiated) response (rapidly hitting "X" and "O" keys) when a "stop signal" (an auditory beep) occurs (Schachar & Logan, 1990; Oosterlaan, Logan, & Sergeant, 1998; Nigg, 1999a). Impaired performance on tasks assessing motor inhibition (specifically, Go-No-Go types of tasks) in ADHD has been associated with structural differences in orbitofrontal and right anterior cingulate brain regions and may be indicative of abnormalities in frontalstriatal circuitry (Casey, 2001).

Although inhibitory deficits have been shown to be specific to ADHD in several studies, they may not be unique to children with ADHD—milder inhibitory deficits may occur in RD also. One study found deficits in RD children on Logan's Stop task (Purvis & Tannock, 2000). These findings were replicated in another recent study, but the effect was not robust to covariance of IQ and ADHD symptoms simultaneously (Willcutt et al., 2001). Nigg (1999) reported a correlation between reading achievement and response inhibition on the Stop task, even though covarying reading ability did not eliminate the ADHD effect. In contrast to these supportive findings, no RD-related response inhibition deficit (measured by commission errors) was found on a task that was similar to the Stop task and required inhibition of response to green circles followed at varying intervals by a red square (Moores & Andrade, 2000).

Studies using Go-No-Go types of tasks provide support for inhibitory deficits in RD but only on tasks that have verbal or phonemic processing requirements, suggesting that they may be confined to the language domain. Moores and Andrade (2000) found that teenagers with RD demonstrated deficits (as measured by commission errors) on a go-no-go type task that used digits, but evidence was less clear when nonverbal stimuli were used (e.g., squiggles). On the nonverbal version of the task, teenagers with RD made significantly more commission errors than comparison children only after reaction time was covaried. Participants reportedly did not have ADHD, but inattention and hyperactivity symptoms were not controlled. Willcutt et al. (2001) found increased commission errors for children with RD on a continuous performance task (requiring response to a white "S" followed by a blue "T"); this finding was not robust to covariates, however. In addition, Kupietz (1990) reported that children with RD demonstrated sustained attention deficits and increased commission errors on a continuous performance task that were characteristic of inattention or short-term memory deficits and decreased with age. Purvis and Tannock (2000), on the other hand, found no evidence of a response inhibition deficit for RD on the Conners Continuous Performance Test (requiring responding to all letters except X). Possible alternative explanations for RD findings on response inhibition tasks like the Stop, Go-No-Go, and Continuous Performance tests include automaticity deficits (Moores & Andrade, 2000) or problems processing two stimuli in rapid succession (Fitch, Miller, & Tallal, 1997; Purvis & Tannock, 2000). For instance, failures to make certain functions (e.g., phonological coding) automatic could lead to a requirement for more effortful/controlled processing of stimuli that limits availability of resources for other tasks. Exploration of this association using tasks other than Continuous Performance tests or the Stop task is sorely needed.

Summary. Deficits in effortful inhibitory motor control currently represent one of the most promising domains for identification of a neuropsychological "marker" of ADHD. Recent findings with regards to RD present a potential problem for theories asserting that certain kinds of inhibitory deficits are unique to ADHD. Due to some of the possible alternative explanations for deficits on the Stop Task, it and other commonly used response inhibition and sustained attention paradigms (e.g., continuous performance tests) will not resolve the issue of whether RD children demonstrate inhibitory deficits like those in ADHD. Alternative methods are therefore necessary. One possibility is that the two groups demonstrate a continuum of inhibitory deficits, such that the severity or type of inhibitory deficit determines predisposition toward the development of one or both disorders. The continuum between automatic and effortful inhibitory processes is one interesting possibility. A continuum of language abilities which may interact with dimensional inhibitory abilities is another such possibility.

Discussion now moves to empirical findings for automatic inhibition and attentional deficits in ADHD and RD. Although not a focus of this study, execution of attention relies, at least in part, on inhibitory processes. Since research in the RD domain has focused more on attentional than inhibitory functioning, this literature may be useful for understanding the relevance of studying inhibitory mechanisms in RD. Attentional deficits in ADHD may also be relevant to relatively automatic inhibitory processes.

Automatic Inhibitory Control and Inhibition for Attention

Halperin and colleagues (1997, 1993) found evidence for two distinct groups of children with ADHD. An ADHD+RD group had increased plasma levels of a noradrenergic metabolite in comparison to an ADHD-only group. The authors hypothesized that increased noradrenergic activity in the ADHD+RD group may be indicative of dysfunction in the posterior attention system and regions of posterior cortex and thalamus that are related to auditory reception and language processing. The ADHD-only group was hypothesized to have deficits in the anterior attention system, leading to executive function and inhibitory failures. A study by Conners and colleagues provided support for this theory. Children classified as having automatic attention deficits on a covert orienting task that required similarity judgements for pairs of letter arrays (i.e., deficits at the 100 ms interstimulus interval) did not demonstrate deficits on an executive function or a vigilance task. In contrast, those classified as having a deficit in voluntary/effortful attention on the covert orienting task (i.e., deficits at the 800 ms interstimulus interval) performed more poorly only on the vigilance and executive function tasks. Automatic attention deficits were therefore asserted to be associated with impaired rapid processing of lexical arrays (unpublished study reported in Schulte, Conners, & Osborne, 1999).

Studies also support attentional deficits in RD. Segalowitz, Wagner, & Menna (1992) reported that poor readers' Contingent Negative Variation attentional ERP, collected during a vigilance task, was related to reading comprehension. This effect was proposed to result from problems recruiting attentional resources to coordinate the linguistic and graphemic processes necessary to learn to read. Immaturity of pathways in the frontal lobe/limbic system was hypothesized as one potential mechanism underlying this finding.

Dichotic listening studies in children with RD are also supportive of attentional dysfunction. Stringer and Kershner (1993) reported that children with RD show the typical right ear advantage for reporting dichotically presented digits orally, but show a weaker right ear advantage for written reporting. The authors asserted that this finding is consistent with a RD-related vulnerability to attentional interference, such that the increased effort/attentional demands associated with a phoneme-to-grapheme processing step interfered with the execution of other cognitive processes. Attentional interference could, in turn, be prevented by an inhibitory mechanism. Children with RD have also been found to demonstrate deficits in attentional shifting in dichotic listening (Kershner & Graham, 1995; Kershner & Morton, 1990). Kershner and Graham (1995) speculated that problems with attentional shifting could produce impairments in the ability to deal with the rapidly changing cognitive requirements for reading. Importantly, although children with RD did not have significantly lower IQ's, their performance in these dichotic listening studies mirrored that of reading achievement-matched controls, suggesting the possibility of delayed development of the mechanism underlying performance on this task. Inhibitory mechanisms that protect attention are still maturing in young children (Dempster, 1993) and thus provide a plausible explanation for these results.

Summary. Evidence in both the ADHD and RD literatures supports the existence of deficits in attention or interference control. The possibility of deficits in an inhibitory mechanism that protects attention in RD has been hypothesized and warrants consideration. Impairments in cognitive inhibitory mechanisms could account for these attentional deficits and would be consistent with problems with interference control. These findings on attentional functioning in both disorders highlight the relevance of studying inhibitory mechanisms, while also demonstrating the relative lack of knowledge or specification of the exact nature of these hypothesized deficits.

Due to the well-documented occurrence of language impairment in RD, examining language processes reliant on inhibition may be one useful area for attempting to clarify whether there are inhibitory deficits in RD and may help explain the high comorbidity between RD and ADHD. Furthermore, examining whether inhibitory impairments in ADHD extend to the language domain may further explain the high rate of co-occurrence between the two disorders. Linkage of ADHD with inhibitory mechanisms during language processing has yet to be attempted. The next section therefore examines these possibilities with regards to language production and language comprehension. Literature that provides evidence for importance of inhibitory processes in language processing will be reviewed first, followed by the limited studies in ADHD and RD that are relevant to potential weaknesses in inhibitory mechanisms that protect language processing.

Inhibition Mechanisms and Language Processing

Developmental Considerations

Dempster (1993) suggested that difficulty with text processing in young children may be due to inefficient inhibitory mechanisms. Given enough time, older children will not only have activated all meanings of an ambiguous word, but will also have inhibited its nondominant meaning (as evidenced by slower responding to a nondominant meaning) and focused attention on the dominant meaning. Children who are in 2nd and 4th grade, however, do not show suppression of the nondominant meaning of the ambiguous word and continue to show facilitation of all meanings at even a 2000 msec delay (Simpson & Foster, 1986; Simpson & Lorsbach, 1983). One possible reason for these findings is that, though automatic spreading activation in lexical access is thought to mature by age 4, control of the conscious allocation of attention doesn't fully mature until 5th or 6th grade.

Much theoretical (and some empirical) work has focused on the connection between language development and development of inhibitory control. Verbal self-regulation is thought to develop between the ages of 1.5 and 5.5 years of age (Harnishfeger & Bjorkland, 1993) and internalized speech subsequently contributes to behavioral self-control. Shelton & Barkley (1994) asserted that the prefrontal impairments theorized to produce disinhibition, inattention, and overactivity in ADHD may also contribute to deficits in syntax, fluency and verbal production. Riccio and Jemison (1998) reported that language impairments mediated the association between inattention and reading ability, thereby suggesting that inattention may have a direct effect on language processing impairments. Although linguistic factors, such as phonological processing, explained the most variance in reading ability in one study, moderate-sized *correlations between inattention and reading achievement* (including phonological processing and comprehension) were also found (Shaywitz, Fletcher, & Shaywitz, 1994). The idea of language impairment as a common link between ADHD and RD thus appears to be plausible, though it has not been directly tested. One possibility is that impaired development of a central inhibitory mechanism, such as one that might support effortful and strategic control of cognition and behavior generally, creates a vulnerability for the development of language processing impairments and, subsequently, reading disorders or the development of ADHD. The development of internalized speech is one area in which hints at such processes are apparent.

Internalized Speech

Current theories of behavioral self-regulation focus on the importance of internalized speech for controlling behavior (Barkley, 1997). Skinner (1953, as described in Barkley, 1997) suggested that behavioral self-control develops through a language-based process that begins with behavioral control by the *language of others*, proceeds to control of behavior by *private speech*, and, finally, results in the use of *internalized speech* for problem-solving. Berk and Potts (1991), furthermore, propose that the development of private speech is reciprocally related to the development of self-control and is moderated by inhibitory mechanisms. Inhibitory control is therefore crucial to the development of internalized speech, which, in turn, leads to the development of greater self-restraint and self-guidance as well as problem-solving and planning abilities (i.e., executive functions).

Inhibition deficits in ADHD may lead to failures in internalized speech development that exacerbate problems with behavioral self-control. At the same time, children with speech and language impairments (including RD) may be delayed in the use of language to control their behavior, placing them at risk for the development of self control problems, including poor ability to inhibit inappropriate behaviors (Riccio & Hynd, 1993).

Children with ADHD have been found to demonstrate more private speech (defined as audible talking not directed towards another person) than comparison children during free play (Copeland, 1979). Furthermore, one study linked poorer response inhibition in ADHD to apparent delays in internalized speech development. Thus, 90 percent of children with ADHD engaged in some kind of *observable* mediating behavior (such as counting out loud or tapping a finger) during performance on a response inhibition task versus only 45 percent of comparison children. In contrast, 80 percent of comparison children reported using a cognitive mediator (e.g., counting in their head) compared to only 30 percent of children with ADHD. Thus, findings suggested that children with ADHD may have been unable to utilize internalized speech to control their behavior (Gordon, 1979).

In addition to the relationship between internalized speech and behavioral control, Damico, Damico, and Armstrong (1999) posited that internalized language also influences the development of cognitive maps/schematas of the world that produce complex thought and abstract thinking. ADHD and language disorders (along with RD), consequently, may share deficits in metacognition and its linguistic or representational underpinnings. Alternatively, as discussed earlier, deficits in executive/inhibition systems may interfere with language use, thereby leading to risk of RD.

Evidence for the relationship between inhibitory mechanisms and language processing will now be discussed in more detail.

Role of Behavioral Inhibition in Language Processing: Language Production

The majority of research on language processing in ADHD has focused on language production. This research has found that ADHD children demonstrate excessive verbal output in unstructured communicative interactions (Zentall, 1988), decreased verbal output and increased verbal dysfluencies as language task organization requirements increase (Zentall, 1988; Ludlow, Rapoport, Bassich, & Mikkelsen, 1980), and problems maintaining and changing topics and in conversational turn-taking (Tannock & Schachar, 1996). Unsurprisingly, in view of their well-known executive and response output problems (Barkley, 1997), the narrative speech of ADHD children is marked by disorganization, lack of information, poor cohesion, and greater inaccuracies than the narratives of unimpaired comparison children (Hamlett, Pellegrini, & Connors, 1987). One study found that ADHD children used fewer descriptive instructions and exhibited increased child-initiated and disruptive speech when required to instruct a listener on the construction of simple block designs. Disruptive speech on this task was manifested by increased interactive communication with the examiner (e.g., by asking more questions and making more commands than necessary for task performance), but was not manifested by increased non-task directed speech. ADHD children also demonstrate problems with self-monitoring of language output. Purvis and Tannock (1997) found significant deficits in event sequencing, original text misinterpretations, and word substitutions on a story re-telling task in comparison to nondisordered control subjects.

Summary

Considerable research supports the existence of inhibitory-related deficits in language *production* in ADHD that seem to be related to already established problems with executive control of motor and behavior output. What is less clear is whether children with ADHD experience problems with language comprehension, a cognitive processing realm more closely related to the demands of reading and the deficits in RD. Just as little research has yet to explore whether inhibitory deficits in ADHD extend into the area of cognitive inhibition, little is known about whether inhibitory deficits in ADHD could produce impairments in language comprehension. Yet, the possibility clearly exists—if inhibitory systems regulating language use are unitary, they may also break down in comprehension. If so, this could provide a link to RD.

Research on the role of inhibitory mechanisms in language comprehension is prominent in the cognitive literature, but, for the most part, has not been extended to clinical research. Linking these bodies of work is thus quite timely. Examination of inhibitory-related language comprehension mechanisms in ADHD and RD has two powerful advantages. First, it provides sorely needed exploration of how inhibition deficits in ADHD might extend beyond well-documented problems in the behavioral domain to impact cognitive functioning. And, second, it may provide insights into the etiology of ADHD+RD comorbidity. A focus on language comprehension thus deserves further consideration.

Role of Cognitive Inhibition in Language Processing: Language Comprehension

Dempster (1993) asserted that text processing is highly reliant on interference control. He described a number of text characteristics that can produce interference, including unrelated statements about the same topic, involvement of the same set of characters in different activities, ambiguous messages with more than one meaning, and irrelevant or contradictory text information. Research on the relationship between cognitive inhibition and language processes is prominent in the cognitive literature (Gernsbacher & Faust, 1991; Faust & Gernsbacher, 1996; Dell & O'Seaghdha, 1994;

Eberhard, 1994; Dempster, 1993). Inhibitory mechanisms have been most well studied in the domain of lexical ambiguity. Neill, Valdes, and Terry (1995) reported that competition among various meanings of ambiguous words involves the same mechanisms underlying stroop and negative priming effects. Lexical ambiguity is proposed to create two incompatible mental representations that compete for control of behavior. The context-appropriate meaning of the word is theorized to receive activation, while the context-inappropriate meaning is suppressed. The result is the eventual selection of the appropriate word meaning. Gernsbacher and colleagues performed a number of lexical ambiguity studies that support the role of suppression in language comprehension. Specifically, they found that response times to targets that were contextually inappropriate meanings of ambiguous words were slower at a short delay than at a long delay (Gernsbacher, Varner, & Faust, 1990, Experiment 4).

This process is promising for better understanding deficits in poor readers. Indeed, a relationship between weak interference control/cognitive suppression and poorer reading comprehension has been demonstrated by a number of studies (Tompkins, Baumgaertner, Lehman, & Fassbinder, 2000; Gernsbacher, Varner & Faust, 1990; Gernsbacher & Faust, 1991, Gernsbacher, 1997). Less skilled comprehenders have been found to have poorer access to recently comprehended information and to generate too many mental substructures during comprehension (Gernsbacher, Varner, & Faust, 1990). Gernsbacher and colleagues hypothesized that the creation of too many mental substructures results from incorporation of irrelevant information into mental representations of text. Lorch and van den Broek (1997) speculated that identifying and creating representations of causal relationships is the core mechanism involved in comprehension. Comprehension and recall of text is influenced by the number of causal connections shared by events in the narrative and whether the event lies along a "causal chain." If impaired suppression mechanisms prevent the development of this causal chain, comprehension deficits may be expected to follow. Supporting this notion, less skilled readers demonstrated recall of fewer important story details (Purvis & Tannock, 1997) and deficits in their ability to draw inferences from text, despite intact sentence-level structural representations and adequate knowledge about sentence content. They are also unable to integrate information from different parts of a story or elaborate their structural representations with topic-related information (Long, Oppy, & Seely, 1997, 1994). It was hypothesized that a bottleneck occurs in less skilled readers at the discourse level of processing.

Findings of impaired suppression in the language domain have been documented in older adults and adults with right hemisphere brain damage, both of whom are hypothesized to experience weakened cognitive inhibitory control. In a series of studies on individuals with right-hemisphere brain damage, Tompkins and colleagues found evidence for a relationship between impaired comprehension and inhibitory dysfunction. On Gernsbacher's ambiguous word paradigm, right hemisphere brain damaged adults failed to demonstrate the expected reduction in reaction time to context inappropriate targets of ambiguous words from short- to long-delay probe intervals (Tompkins et al, 2000). This relationship was specific to right-hemisphere brain damaged individuals when compared to individuals with left hemisphere brain damage (Tompkins, 1991). Individuals with right hemisphere brain damage also tend to maintain incorrect inferences about information later negated in text, while simultaneously incorporating correct inferences (Tompkins, Lehman, & Baumgaertner, 1999). Thus, discourse comprehension deficits are particularly apparent under conditions requiring resolution of multiple or competing interpretations. Similar findings have been reported in older adults (Hasher & Zacks, 1988). Hamm (1992) found that older adults continued to incorporate corrected misinformation into their inferences about a passage, despite also incorporating the corrected information.

Although the performance of children with ADHD on such comprehension-suppression tasks is unknown, there is reason to think that they may show weakened suppression processes. For one thing, behavioral and cognitive deficits in ADHD have often been compared to those of individuals with right hemisphere brain damage (e.g., Heilman, Voeller, and Nadeau, 1991). As such, findings of impaired discourse comprehension in right brain damaged individuals may provide a model for language dysfunction in children with ADHD. Although very little research has examined either text or language comprehension in ADHD, those findings that do support comprehension deficits are consistent with possible inhibitory impairments.

Further, some studies suggest that ADHD children make less use of causal connections in story narratives, leading to poorer overall story comprehension and retention of minor story details at the expense of more important ones (Lorch et al., 1999). Other studies, however, report no significant differences for ADHD children in the recall of story narratives (Purvis & Tannock, 1997). Processing demands may influence whether impairments in the mechanisms underlying reading comprehension are manifested in comprehension impairments. For instance, children with ADHD demonstrated impaired recall of television stories under conditions of divided attention and derived even less benefit from causal connections (Lorch et al., 1999). Lorch and colleagues (1999) hypothesized that such deficits may result from weakness in inhibitory mechanisms, allowing interference with selection of important story units as a result of failure to suppress irrelevant ones. Though one study found children with ADHD to have poor reading comprehension despite intact word identification and phonological processing skills (Brock & Knapp, 1996), another study indicates no significant differences for ADHD children in the recall of story narratives (Purvis & Tannock, 1997).

In addition, the use of more ambiguous references by children with ADHD (as well as by children with RD) on a story re-telling task has been posited to support deficits in the construction of mental representations of comprehended material. These ambiguities were speculated to support problems in the organizational cohesion of information across sentences. These problems were found for the reproduction of the stories (Purvis & Tannock, 1997). As a result, evidence seems to support the idea that inhibitory deficits may create difficulties for developing mental representations that are necessary for reading comprehension. Although findings of unimpaired comprehension appeared in some studies of ADHD, the possibility exists that traditional methods of assessing reading comprehension may not be sensitive enough to detect ADHD impairments, because they do not specifically assess cognitive inhibition mechanisms. "On-line" methods of measuring comprehension in children with ADHD may prove useful for identifying more subtle effects of inhibitory deficits, if they exist.

Conclusion

Several distinct facts feed into the current research focus: (a) the proposed relationship between internalized speech (a language function) and behavioral self-control, (b) the well-documented incidence of inhibitory failures in response output in ADHD, and (c) evidence for the importance of cognitive suppression mechanisms in effective language comprehension, as well as (d) clear comprehension problems in RD, and (e) possible comprehension problems in ADHD. Together, these facts suggest that studying language comprehension functions that require inhibition may provide one avenue for better understanding cognitive impairments in ADHD and RD. In particular, little research has addressed the role of inhibitory functioning in language *comprehension* in ADHD or, for that matter, in RD (despite all the studies using informal classifications of "poor comprehenders"). This absence occurs despite considerable support for a relationship between language comprehension and inhibitory functions in the cognitive literature. Since comprehension is a cognitive rather than a production-oriented process, the type of inhibition utilized in this domain may differ from that used in discourse production and may be more related to interference control and cognitive suppression. This direction departs from the usual and rather well-established output problem in ADHD to look at an unstudied domain of ADHD cognition.

Delineating the primary language deficits in each disorder is important, because it may reveal areas of "overlap" in the cognitive impairments (or "impairment profile") in each disorder and thus provide clues as to the etiology of their comorbidity. Which deficits exist in either ADHD or RD or both could further define the nature of cognitive impairments in the two disorders as well as provide an explanation for the high incidence of comorbidity between them. In contrast, finding no indications of deficient cognitive suppression in ADHD children would help narrow the scope of inquiry regarding the nature of language impairments in ADHD. It would also provide further support for those theories and empirical findings suggesting that ADHD is primarily a disorder of behavioral (output) disinhibition—even in the domain of language. Or, alternatively, it would help rule out the language domain as a possibility for shared deficits, leaving other domains (e.g., auditory processing and working memory) for future study. Thus, studying this domain in relation to ADHD is also important in its own right, regardless of RD.

The potential contributions of this study are as follows. 1) Studying the performance of children with ADHD on inhibitory language tasks may help to further clarify the nature of their language impairments and, by extension, clarify how self regulation fails in that disorder. 2) Clearer delineation of the mechanisms by which inhibition and language comprehension interact in ADHD may help to identify areas of commonality to RD-related language impairments and thus may provide hints as to the etiology of the frequent co-occurrence of the two disorders. 3) Examining whether children with RD have impairments on inhibitory-reliant language tasks may provide additional evidence as to whether there are inhibitory deficits in this disorder.

METHODS

Participants

Participants were 97 children between the ages of 7 and 14 (57 boys and 40 girls) with a mean age of 10.2 $\pm$ 1.2 years.[1] Sample characteristics are summarized in Table 1.

Table 1. Demographics Description: Means (SD).[2]

	Control	ADHD-Only			RD-Only	RD+ADHD	
		ADHD-C	ADHD-I	Sub-Threshold/ Situational		ADHD-C	ADHD-I
N	27	28	7	14	13	4	3
Age	10.3 (1.4)	9.9 (1.0)	10.0 (1.0)	10.9 (1.1)	10.5 (1.3)	11.0 (1.2)	10.3 (1.2)
Sex (% Male)	41.0	79.0	57.0	50.0	54.0	75.0	67.0
Ethnicity (% White)	58.0	69.0	83.0	50.0	100	100	67.0
Estimated IQ	107.0 (16.5)	100.4 (15.4)	98.1 (13.9)	107.2 (11.5)	103.5 (16.0)	98.3 (8.2)	102.7 (30.1)

Children were community volunteers recruited through invitation letters sent to parents of children in the regional schools and through newspaper and radio advertisements. Children whom the school district had classified as ADHD or RD, as well as regular education children, were identified by the school to receive invitation letters without revealing their identity to the investigator. Children with neurological impairments, other serious medical or psychiatric conditions, estimated Performance IQ below 75 (or Full Scale IQ below 70), uncorrected visual or hearing impairments, and those who did not speak English as their first language, were excluded from the study.

[1] The targeted age range was 9 and older; thus, only one 7 year-old and three 8 year-olds were included in the total sample.

[2] Note that 1 child not included in this table met criteria for the Hyperactive-subtype of ADHD. In addition, 5 RD children met criteria for ADHD by parent report only (i.e., "situational ADHD"), but were included in the pure RD group based upon their pattern of reading achievement, language, and learning problems (to be further described below).

Note that 2 ADHD children did not meet IQ cut-off 's, so were excluded from all cognitive task analyses.

Diagnostic Procedure

ADHD Classification

Diagnosis of ADHD was made by: 1) parent report on the Diagnostic Interview Schedule of Childhood-IV (DISC-IV; Shaffer et al, 1993), a structured diagnostic parent interview assessing DSM-IV symptomatology of ADHD (and other DSM-IV disorders), and 2) was supplemented by an "OR-algorithm" that followed the DSM-IV field trials validity data (Lahey et al., 1994). This "OR" algorithm summed the total number of parent-rated symptoms on the DISC-IV with non-overlapping teacher-rated DSM-IV symptoms on the ADHD Rating Scale (DuPaul, 1998).

Even if full criteria (i.e., 6 inattention / 6 hyperactivity symptoms) were met by parent report on the DISC-IV, final diagnosis also required teacher support (by exceeding clinical cut-offs) on at least one common ADHD rating instrument (including the DuPaul ADHD Rating Scale [DuPaul, 1998], short form of the Conners Rating Scale [Conners, 1997], and the Behavioral Assessment System for Children [Reynolds & Kamphaus, 1992])[3]. Symptoms also had to have persisted for more than six months, been present in both home and school settings, appeared by seven years of age, and have produced functional impairments (determined by DISC-IV impairment items). DISC-IV interviews were conducted by trained interviewers during either an initial half-hour phone call (which was then completed during the child's visit) or during an initial two-hour office

[3] Children with a prior ADHD diagnosis who were always stimulant medicated during school hours were included without teacher questionnaire support if full criteria were met on the DISC-IV.

visit.[4] Parents and teachers were always asked to make ratings according to the child's behavior when unmedicated (if possible). Thus, every effort was made to assure that children met DSM-IV criteria for ADHD, including use of multiple informants and a structured diagnostic interview.

RD Classification

Following the suggestion of Sattler (1992), RD diagnosis was made utilizing a regression equation incorporating IQ and the mean of word recognition, spelling, and phonological decoding achievement. The regression method is more accurate than a "simple-discrepancy" method of diagnosing RD, because it accounts for regression to the mean with higher and lower IQ's. The equation used in the current study was a modified version of that used by Pennington, Groisser, and Welsh (1993).

$$\text{Reading Quotient}^{6} = \frac{(\text{WIAT Reading SS} + \text{WIAT Spelling SS} + \text{Word Attack SS})/3}{(\text{Expected IQ for Age [100]} + \text{Estimated FSIQ})/2}$$

RD was diagnosed for cut-off score's less than 0.85 (i.e., mean achievement one standard deviation below the average of actual IQ and population IQ average), which was more conservative than Pennington et al.'s cut-off of 0.90. Note that, consistent with Pennington et al's procedure, this regression equation and cut-off score allowed some high IQ individuals with reading scores within the average range to be included as RD.[7]

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[4] The interviewer was always blind to child performance on tasks, although not always to study hypotheses.
[5] It may not be possible for interviewer to be blind to study hypotheses, but the interviewer will be blind to child performance on tasks.
[6] Use of Standard Scores (SS) rather than age-equivalents is the main difference between this equation and that used by Pennington et al.
[7] 2 RD children had reading scores in the average range.

Supplemental reading measures assessed reading comprehension skills and expressive and receptive language (described below).

Classification of "Pure" RD vs. RD+ADHD Children. One complication in determining group classifications was the very high rate of subclinical attention problems in many RD children. A number of these children (N=5) met criteria for ADHD-I by mother report on the DISC, but teacher ratings did not support an ADHD diagnosis (i.e., these children had "situational" ADHD). These children were ultimately included in the "pure RD" group based upon their pattern of reading achievement, language, and learning problems, which suggested that they had more severe reading problems than did RD children who did not meet criteria for situational ADHD. By this rationale, higher mother-rated inattention may stem from these children's increased academic struggles, likely manifested by greater avoidance behavior around academic tasks (e.g., homework) in the home setting. Consistent with this interpretation, RD children with situational ADHD accounted for the higher incidence of ODD in RD children (refer to Table 4 in Results section, p. 72).

The statistical significance of differences among pure-RD children with and without situational ADHD was difficult to evaluate due to the small sample sizes (N=5 and N=8, respectively). However, means for these groups are reported in Table 33 in Appendix A, along with a more detailed discussion of trends in this data (p. 171).

Non-Disordered Control Group Classification

The comparison group met all inclusion criteria, but had 4 or fewer ADHD symptoms in either domain by the "OR" algorithm (to exclude borderline ADHD cases) and a Reading Quotient above 0.85. Incidence of oppositional and conduct problems and anxiety and depression were also measured and children with any of these diagnoses were excluded from the Control group. A number of children (N=14) were "subthreshold" for ADHD diagnosis (i.e., they were 1 or 2 symptoms short of diagnosis for ADHD-I or ADHD-C or met criteria situationally only) and were consequently excluded from group analyses. This subthreshold group was, however, included in dimensional analyses.

Procedure

Children completed the research battery at Michigan State University during one 2.5 to 3 hour visit to campus. A portion of children completed this visit as the first of a 3-visit, larger-scale, study of child ADHD. After parental consent was obtained, children assented to the testing procedure and were administered the tests in a standardized order (the key experimental tasks were administered in a randomly counter-balanced order). Frequent breaks were interspersed within the testing session. Those children taking stimulant medications were tested after a minimum of a 24- or 48-hour wash-out period for short-acting and long-acting stimulant medications, respectively. Such a washout period is generally considered adequate in the literature in view of the half-life of these medications (on the order of 2-6 hours). Time since last medication dose was recorded and was available for secondary analyses. Following the completion of the testing session, children were paid $10 and were given some free-time to play computer games. Mothers received $40 and were given written or oral feedback on the child's test results. Teachers were paid $15 for completion of behavioral ratings. Those families screened out after completing the initial packet of behavioral ratings were paid $5, while families screened out after the second screening stage (telephone DISC-IV interview or 2-hour office visit) were paid $20 for participation to that point.

Measures

Descriptive and Background Measures

Intelligence

Wechsler Intelligence Scale for Children-III. A five-test short form of the Wechsler Intelligence Scale for Children-III was used to estimate intelligence. This short-form has a reliability of .95 and validity of .86 (Sattler, 1992), and consists of the Vocabulary, Similarities, Block Design, Information, and Picture Completion subtests.

Achievement

Wechsler Individual Achievement Test (WIAT). Word recognition and spelling were assessed using the Wechsler Individual Achievement Test (The Psychological Corporation, 1992), which is co- normed with the WISC-III normative sample.[8]

Woodcock-Johnson Psycho-Educational Battery-Revised (WJ-R). The WJ-R Word Attack and Passage Comprehension subtests (Woodcock & Johnson, 1989,1990) were used to measure phonological decoding (i.e., nonword reading) and reading comprehension.[9]

The WJ-R Passage Comprehension test assesses reading comprehension via ability to identify a missing key word in the context of increasingly semantically and syntactically complex passages (i.e., high cloze passages). This measure provided an

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[8] For the reading subtest, average split-half reliability for children between the ages of 5 and 17 (N=3899) is .92.

[9] Internal consistency (split-half reliability) of the Word Attack subtest ranges from .88 to .95 in children between the ages of 6 and 18. Median reliability of the Passage Comprehension subtest for children between ages 5 and 19 is .83.

index of general comprehension skill for comparison to experimental task performance. Independence from reading comprehension ability would provide support for the hypothesized inhibitory effects on experimental tasks. Secondary analyses examined correlations between reading comprehension and experimental task performance (regardless of diagnostic classification) to ascertain whether Gernsbacher and colleagues' (2001) hypothesis about the relationship between comprehension and suppression skill extends to a child population. In validity studies for the WJ-III (McGrew & Woodcock, 2001), children with ADHD had poorer comprehension on this subtest than non-impaired comparison children.

Language

Clinical Evaluation of Language Fundamentals-3 (CELF-3). Estimates of receptive and expressive language ability were obtained from the Concepts and Directions and Recalling Sentences subtests of the Clinical Evaluation of Language Fundamentals-III (Semel, Wing, & Secord, 1995). The Concepts and Directions subtest assesses ability to interpret and follow commands of increasing length and complexity (e.g., *"Point to the little triangles. Then point to the big circles."*). On the Recalling Sentences subtest, children must repeat increasingly longer and more complex sentences verbatim (e.g., *"The catcher caught the ball and the crowd cheered loudly."*).

Both tests also have high working memory demands. The Recalling Sentences subtest, because of its requirements for reconstituting sentences for verbatim oral reproduction, was believed to have a particularly strong working memory requirement (Barkley, 1997) and will therefore often be referred to as a measure of both expressive language and working memory.

Experimental Tasks

The two experimental tasks used in this study were measures of language comprehension hypothesized to challenge cognitive inhibition. The Ambiguous Words Task served as a measure of interference control (relying upon both automatic and effortful suppression mechanisms), whereas the Garden Path Task served as a measure of ability to revise incorrect syntactic representations and their resultant misinterpretations (believed to rely upon more effortful suppression mechanisms).

An important caveat with regards to most measures of inhibitory function also applies to these tasks, however. For both of these tasks, alternative explanations can be made for the mechanisms underlying task performance. For instance, decay of activation or boosting of activation could also provide a reasonable explanation for task effects. This debate remains unresolved in the cognitive literature (Dagenbach & Carr, 1994). Given that it would be impossible to find any task that has a *proven* inhibitory mechanism underlying performance, the current tasks were chosen because of their hypothesized inhibitory processes and the fact that their data are consistent with such an explanation.

Visual and Auditory Task Versions. WIAT word reading norms (The Psychological Corporation, 1992) indicate that a child aged 10:0 (the target age of children recruited for this study) who reads 1 ½ standard deviations below average for his/her age (SS=85) would be reading at a mid-second grade level. All stimuli were therefore designed to be readable at an early second grade level. Stimuli were piloted and tested for readability in six children from the ages of seven to ten[10] to determine the

[10] Children were believed to have had average intelligence and average to below average reading abilities, although this was not formally tested.

relative ease with which stimuli could be decoded. Stimuli were adjusted until easily decoded and comprehended by seven-year-olds.

Contrary to initial expectations, most of the RD children included in the study had reading levels below the second grade level, however. Since it was not possible to administer auditory task versions to all subjects (many subjects had already been collected on the visual version), an additional auditory version of both tasks was created. Children who read below a second grade level (identified by a cut-off raw score of 25 on the WIAT word recognition subtest) were then administered the auditory version of the task, while all other children took the visual version of the task. The auditory task versions utilized pre-recorded stimuli (to maintain standardized administration) that were presented via computer in conjunction with the visual stimulus. The auditory task was in all other ways analogous to its visual version.

Measure of Interference Control: The Ambiguous Words Task (Gernsbacher, Robertson, & Werner, 2001)

The Ambiguous Words Task employed sentences containing homonyms to measure interference control during lexical ambiguity resolution. Lexical ambiguity studies that require plausibility judgments find increased reaction times and error rates to homonym targets following their alternate-meaning primes (Simpson & Kang, 1994; Gernsbacher, Robertson, & Werner, 2001). This relative "Cost" in processing different-meaning targets has been argued to reflect functioning of automatic inhibition mechanisms. In contrast, performance is facilitated when the homonym sentences maintain the same meaning over the two presentations. Gernsbacher, Robertson, and Werner (2001) reported that college-aged poor comprehenders demonstrated significantly reduced "costs" (i.e., inhibitory deficits) versus good comprehenders when processing such sentences and interpreted these differences to reflect impairments in inhibitory control. A rough estimate of effect sizes produced with this measure for the Cost comparison in average comprehenders is d=1.26 (f=.63) for RT and d= .98 (f=.49) for accuracy. These are "large effects" according to Cohen, 1992.

Stimuli. Modeled on that of Gernsbacher, Robertson, and Werner (2001), the task used in the current study consisted of 37 pairs of experimental sentences ending in a homonym (12 "Different," 12 "Same," and 13 "Nonsense") and 60 pairs of filler sentences (also ending in a homonym) on which children were required to make a meaning judgment regarding whether the sentence "makes sense." The first sentence of each pair acted as a prime and the second sentence as the target. For example, the target sentence "She blew out the match" would be preceded by one of 3 prime sentences: a **same-meaning** prime (e.g., "She lit the match"), a **different-meaning** prime (e.g., "She won the match"), and a **nonsense-meaning** prime (e.g., "She sang the match"). Same-meaning primes were designed to produce a benefit in reaction time or to decrease the percentage of errors compared to nonsense-meaning primes. Different-meaning primes were designed to produce a "cost" in reaction time or an increase in percentage of errors. Given the "yes"-biased correct answers on both primes and targets in the Same and Different conditions, filler sentences balanced out the required response patterns to prevent children from developing response strategies. Filler sentences therefore consisted of 12 "no-yes" items, 24 "yes-no" items, and 24 "no-no" items. Response times and accuracies (recorded via computer) following nonsense-meaning prime sentences (which were designed to bias neither homonym meaning) were compared to both same-meaning and different-meaning primes.

In creating the stimuli, homonyms were selected from the University of Alberta norms for homograph frequency published by Twilley, Dixon, Taylor, and Clark (1994), as well as from stimuli used by Gernsbacher, Robertson, and Werner (2001). Stimuli were created using homonyms that were unbalanced (i.e., the alternate meanings of the homonym had unequal frequencies). Thus, one homonym meaning was "dominant" and the other meaning was "subordinate". In the current task, the target sentence always used the subordinate homonym meaning. "Different" condition stimuli therefore consisted of a dominant-meaning prime sentence and a subordinate-meaning target. Stimuli in the "Same" condition consisted of a subordinate-meaning prime and subordinate-meaning target, while stimuli in the "Nonsense" condition consisted of a no-meaning prime and subordinate-meaning target.

Based on findings from Gernsbacher and colleagues' (2001) study, the rationale for using subordinate targets was related to the desire to maximize potential "Costs" with lower frequency words, while at the same time preserving the possibility of detecting "Benefits".[11] Several studies of homograph resolution have argued for functioning of inhibitory mechanisms even under these conditions (Simpson & Adamopoulos, 2001).

Use of subordinate targets did, however, have some potential pitfalls with regard to measuring inhibitory control. In particular, use of a dominant, high-frequency, homonym in the prime sentence might produce very high levels of activation that would carry into target processing (or make it unnecessary to suppress the context-inappropriate

[11] In Gernsbacher et al's studies, the use of balanced homonyms produced somewhat smaller costs for the Nonsense versus Different condition, whereas use of dominant targets did not produce benefits for the Nonsense versus the Same condition.

subordinate meaning during prime processing). Slower responding or poorer accuracy to targets could then also be interpreted as resulting from *interference* from the highly activated dominant prime rather than to *inhibition* of the subordinate-meaning homonym during prime processing. This potential confound in experimental manipulations will be kept in mind when interpreting results. As will be addressed in the Discussion, even if findings better match an activation-interference interpretation, it might be possible to detect inhibitory functioning during *target* rather than prime access.

Task Construction. Words were selected for ease of reading, and all sentences were designed to be appropriate for children reading at a second grade level. Stimuli were initially piloted on 6 children who were normal readers (ages 7-10, grades 2-4) to determine appropriateness of stimuli difficulty, and a number of stimuli were then modified prior to finalization of the task.

When experimental stimuli were created, sentence pairs for each condition (i.e., Same, Nonsense, Different) were constructed for every homonym and were then randomly assigned to one of three lists. Ultimately, however, one list was chosen for administration to *all* children, such that all children received exactly the same items (although their order of presentation was randomized). This approach prevented examination of specific stimulus item effects across all subjects. However, despite this task limitation, using one list was ultimately preferred to maximize statistical power in this small sample.

Procedure. The task procedure was as follows: To ensure that children understood the concept of a "nonsense" sentence, task instructions were presented with training and feedback on how to determine whether a sentence made sense. Task instructions can be found in Appendix C (p. 215). Stimuli were presented via computer and children were required to press a "yes" or "no" key to indicate their meaning judgment. Prime sentences appeared in their entirety following a brief (750 ms) "+" cue and remained on the screen until the child made a response. The sentence was then replaced with another brief "+" cue, followed by presentation of the target sentence.[12] Children first completed a practice block of 5 sentence pairs and were offered accuracy feedback after each sentence (this feedback was given only for practice sentences). Experimental sentences were presented in 5 blocks of 20 pairs (with the exception of the final block which had 17 pairs), and children were offered a break after each block.

Entire task performance took approximately 20 minutes.

Measure of Revision: Garden-Path Sentences Task (Christianson, Hollingworth, Halliwell, & Ferreira, 2001)

The Garden Path Task was used to examine ability to revise misinterpretations arising from a misleading structural (syntactic) ambiguity and to arrive at a correct sentence interpretation during language comprehension (both written and spoken). The effect of semantic plausibility and syntactic structure on the ease with which misinterpretations could be revised was also examined. Very little research to date has examined sentence processing in children. Trueswell, Sekerina, Hill and Logrip (1999) examined resolution of temporary syntactic ambiguities in kindergarten-aged children by examining eye movements during response to spoken instructions. They found that these children showed extreme resistance to revising incorrect interpretations of temporarily ambiguous sentences and hypothesized that resource limitations (which may rely on inhibitory mechanisms) were responsible for this pattern of performance. Thus,

[12] On the auditory task, sentences were presented both visually and auditorily with the same procedure.

inhibition failures would be manifested by persistence of misinterpretations despite cues regarding their incorrectness.

Stimuli. A full list of task stimuli can be found in Appendix D (p. 217). Methodology was based upon that of Christianson, Hollingworth, Halliwell, and Ferreira (2001) but was simplified for use in a child population. Experimental stimuli consisted of 28 experimental garden path (subordinate-matrix) sentences and 28 control non-garden path (matrix-subordinate) sentences. Conditions varied along two dimensions, one of which was semantic and the other of which was syntactic.

Table 2. Example Sentences by Condition for the Garden Path Task.

		Condition	Item Example
Garden Path	**OT**	Plausible	As Joe walked the dog napped. Q: Did Joe walk the dog?
		Implausible	As the ape ate the tree grew. Q: Did the ape eat the tree?
	RAT	Plausible	As Betty woke up Daddy was sleeping in the den. Q: Did Betty wake up Daddy?
		Implausible	As the man shaved the cat sat in the tree. Q: Did the man shave the cat?
Non-Garden Path	**OT**	Plausible	The water cooked as Deb drank. Q: Did Deb drink the water?
		Implausible	The worm swam in the lake as Jack ate. Q: Did Jack eat the worm?
	RAT	Plausible	The baby was in bed as the boy washed. Q: Did the boy wash the baby?
		Implausible	The kids swam in the pool as Frank dried off. Q: Did Frank dry off the kids?
Filler			As Daddy made the food the kids played in the den. Q: Did Daddy make the tape? The boys took their pens as they left for jail. Q: Did the boys leave for jail? As Pam was feeding the fish she saw a UFO. Q: Did Pam see a UFO?

OT: Optional Transitive; RAT=Reflexive Absolute Transitive

The semantic dimension manipulated "plausibility" of garden path interpretations. **Implausible** condition sentences were those in which 1) the subordinate verb and noun phrase had an implausible relationship (i.e., *"ate the tree"; "shaved the cat"*), and 2) the resulting garden path misinterpretation was itself also implausible: (e.g., *"As the ape ate the tree grew."*). In contrast, **Plausible** condition sentences had 1) a plausible relationship between the subordinate verb and noun phrase (e.g., *" walked the dog"; "woke up Daddy"*), but 2) a resulting garden path misinterpretation that was still implausible (e.g., *"As Joe walked the dog napped"*—In this sentence, the garden path interpretation is still implausible because Joe can't walk the dog and have it nap simultaneously). Note that for both plausible and implausible conditions, the matrix clause itself is plausible (i.e., a dog napping; a tree growing).

Conditions also varied syntactically based upon Optional Transitive (OT) and Reflexive Absolute Transitive (RAT) verb types. RAT verb conditions differed syntactically from OT verb conditions in that RAT verbs are understood reflexively (even without an object). Thus, if a RAT garden path sentence is parsed correctly, it can't be inferentially linked to an unspecified object as an OT verb can. For example, the **RAT** sentence *"As the man shaved the cat sat in the tree,"* if parsed correctly, *cannot* produce an inference that the man shaved the cat; he must shave *himself.* In contrast, in the **OT** sentence, *"As the ape ate the tree grew,"* one might still infer that the ape ate the tree due to the inference that the ape must be eating *something* and thus was likely eating the banana. Since RAT verbs can also retain their transitive structure without a direct object (or can utilize their implicit reflexive object—e.g., himself/herself), garden path sentences utilizing RAT verbs do not need to be completely syntactically revised to allow for semantic reinterpretation or verb-noun phrase thematic role re-assignment. Put another way, RAT verbs are not as resistant to reinterpretation—perhaps because the verb and object are not as strongly linked (from an activation perspective, for example, the causal connection linking a RAT verb and object may be weaker—perhaps due to competition from an alternate implicit object [e.g., herself/himself]).

There were also 36 filler sentences comprised of both subordinate-matrix and matrix-subordinate sentences that differed from garden path sentences by the addition of an extra noun phrase. These filler sentences also differed according to whether the comprehension questions probed: a) the object of the subordinate clause or the subject of the matrix clause (e.g., in a sentence such as *As Pam was feeding the fish she saw a UFO* the question might be: 1) *Did Pam feed the fish?* or 2) *Did Pam see a UFO?*), and b) a "true" subject or object of the sentence or a "foil" (e.g., *Did Pam feed the lion?).* Finally, filler sentences also varied according to their pragmatic plausibility, with some sentences requiring a "yes" answer to implausible relationships (e.g., *The mom played the socks as she watched the news. Q: Did the Mom play the socks?*).

Task Construction. Items were piloted on 6 children (not the same children on which the Ambiguous Words Task were piloted) prior to task finalization and modified as necessary. As in the Ambiguous Words Task, two item lists were initially created by randomly assigning garden path sentences and their non-garden path pair to one list or the other. Two maximize statistical power, one list was then chosen for administration to *all* children.

Procedure. Children viewed sentences on a computer screen and answered yes/no comprehension questions about the sentence. Task instructions are presented in

Appendix C (p. 215). Prior to task administration, children were coached on distinguishing pragmatic inferences from literal sentence interpretation and encouraged to make sure they interpreted sentences literally (e.g., to answer "no" to *The water cooked as Deb drank* since the sentence does not directly state that she has).

Sentences appeared on the computer screen in their entirety. Children controlled the presentation rate and pressed a key to advance to the comprehension question.[13] Total administration time was approximately 20-30 minutes, with opportunity for breaks interspersed throughout. Errors served as the primary variable of interest. Inhibitory deficits on this task would be manifested by increased errors versus comparison children. Since sentence length among conditions was not controlled, RT's were not used in analyses.

Plan of Analysis

Data for the Ambiguous Word and Garden Path tasks were analyzed separately in two stages: 1) Dimensional analyses (both correlation and regression) exploring the relationship of reading, attention, and hyperactivity to task performance, and 2) Categorical Analyses of group effects using analyses of varience to compare 1) ADHD and Control groups, 2) RD and Control groups, and 3) ADHD and RD groups. Details of these analytic comparisons will be presented in more detail within the Results section.

Results were always re-checked after separately covarying for missing data replacement, IQ, age, and symptoms of other commonly co-occurring disorders (e.g., oppositional defiant and conduct disorder). Exploration of sex effects was examined by including sex as a between subjects factor. Using the procedure of many ADHD+RD

[13] On the auditory task, children did not control presentation duration of the sentence but had unlimited time to answer the comprehension question. It is therefore possible that the memory demands of the task were higher for these children.

comorbidity studies (Pennington, Groisser & Welsh, 1993, Willcutt et al., 2001, Nigg et al., 1998), descriptive characteristics of the comorbid ADHD+RD group (e.g., language and reading achievement) were addressed by re-running analyses using a 2x2 design (ADHD present, RD present).

To increase power to detect differences in this small sample, composite indexes were used to examine task effects where possible. Overall, effect sizes for the various experimental manipulations in this study were similar to those reported in the literature for executive functioning tasks (typically d=.60 or $eta^2 = .08$ or larger) comparing ADHD versus Control children (Pennington & Ozonoff, 1996). Thus, the utility of these cognitive tests for examining functioning in ADHD children is equivalent to those of traditional executive function measures. With the sample size and analytic design used here, power to detect effects in all key comparisons was above 0.80.

Although the large number of analyses used in this study somewhat increased the risk of a Type-1 error, it is proposed that correcting for number of analyses by adjusting the significance level (e.g., with a modified Bonferoni correction setting alpha = .01) would not be helpful. Due to the study's small sample size, adjusting the significance level would lower power and thus increase Type-2 errors. Furthermore, specific predictions are defined *a priori* in accordance with theoretical proposals, arguably reducing the need to control for chance findings. Therefore, it was decided that the significance level not be altered from alpha = .05, although the possibility of Type-1 errors will be considered in task interpretations.

Data Reduction and Data Cleaning

Missing data was imputed using the estimation maximization (EM) algorithm, which is one form of maximum likelihood estimation (Shafer & Graham, 2002). This imputation method is believed to provide better estimates of missing data than mean substitution or regression-based replacement methods. Across all variables (cognitive tasks as well as parent and teacher behavioral ratings), 5.8 % of data was missing. To compensate for the potential effects of estimation, a missing data variable was created and covaried in all subsequent analyses as recommended by Cohen and Cohen (1983), enabling the effects of substitution to be both assessed and removed. Covarying for the effect of missing data did not affect the results.

Experimental Hypotheses and Predictions

Hypothesis:

If children with ADHD have impairments in cognitive inhibition then they would be likely to experience problems in higher-order language comprehension (e.g., drawing inferences from text and revising or updating text interpretations). Furthermore, if cognitive inhibition impairments contribute to the language processing problems of children with RD, then they should also demonstrate impairments in higher-order language comprehension. RD and ADHD should therefore be associated with similar patterns of impairment in higher-order language processing that will provide clues as to whether they share a common underlying neurocognitive deficit.

Predictions:

1) ADHD children will demonstrate deficits on both the Garden-Path and Ambiguous Words tasks. Likewise, higher levels of inattention and hyperactivity will be dimensionally associated with poorer performance on these tasks. .

a) ADHD group differences or dimensional associations between inattention/ hyperactivity and performance on the Ambiguous Words Task would reflect interference control problems suggestive of impairment in more automatic cognitive inhibition.

b) ADHD group differences or dimensional associations between inattention/hyperactivity on the Garden Path Task would reflect impairments in correction of misinformation and in the more effortful aspects of cognitive inhibition.

c) If ADHD diagnosis and inattention/hyperactivity are not associated with such deficits, results would be consistent with the idea that ADHD is simply a motor inhibition/output deficit and does not involve problems with either cognitive inhibition or language comprehension.

2) RD children and dimensional measures of reading ability will also be associated with deficits on the Ambiguous Words and Garden-Path tasks. RD group differences will reflect: a) lower-order language impairments as well as b) higher-order inhibition deficits. Support for higher-order inhibition deficits will be reflected in failure of language or reading impairments to entirely account for group differences.

ADHD and RD children will show both similar and different patterns of deficits on these tasks. RD children will show patterns of performance suggestive of both lower-order and higher-order language processing deficits whereas ADHD children will have only higher-order processing problems.

RESULTS-Part I

Note about the Organization of Sections

Extensive amounts of data are reported in the following section. To orient the reader to the results, the general structure of this section follows. The first section describes sample characteristics in some detail, due to their direct bearing on later data interpretation regarding ADHD and RD (and ADHD+RD comorbidity). The second and third sections report results for the Ambiguous Words and Garden Path tasks, respectively. These sections are organized according to: 1) an exploration of task effects (e.g., whether the task worked as expected), 2) dimensional analyses (both correlational and regression) that address hypotheses concerning the relationship of inhibition to attention problems and reading, and 3) group analyses (ANOVA's) that address hypotheses regarding whether ADHD and RD have overlapping cognitive deficits. To streamline and focus results, findings peripheral to the primary hypotheses were placed in Appendix A as background. The reader will be referred to the Appendix for further information when appropriate.

Sample Description

Demographics

Sample characteristics are in Table 3 (below). Group differences on demographics variables were examined for key diagnostic groups (i.e., Control, ADHD-C, ADHD-I, pure RD), using 3x2 univariate ANOVA's with ADHD group (Control, ADHD-C, ADHD-I) and RD group (RD yes, no) serving as between-subjects variables. RD group and ADHD group were used as separate, between subjects, factors to examine comorbid ADHD+RD effects in a preliminary manner. Post-hoc analyses compared discrete groups (rather than RD and ADHD group interactions) and significant findings are detailed via superscripts as explained in the table footnotes.

Table 3. Demographics Description: Means (SD).[14]

	Control	ADHD-Only			RD-Only	RD+ADHD	
		ADHD-C	ADHD-I	Sub-Threshold/ Situational		ADHD-C	ADHD-I
N	27	28	7	14	13	4	3
Age	10.3 (1.4)	9.9 (1.0)	10.0 (1.0)	10.9 (1.1)	10.5 (1.3)	11.0 (1.2)	10.3 (1.2)
Sex (% Male)	41^{B}	79^{AB}	57	50	54^{A}	75	67
Ethnicity (% White)	58^{C}	69^{D}	83	50	100^{DC}	100	67
Estimated IQ	107.0^{E} (16.5)	100.4^{E} (15.4)	98.1 (13.9)	107.2 (11.5)	103.5 (16.0)	98.3 (8.2)	102.7 (30.1)

$^{A}\chi^2(1, 41) = 2.62$, $p=.05$; $^{B}\chi^2(1, 55) = 8.20$, $p<.01$; $^{C}\chi^2(1, 41) = 2.62$, $p<.01$; $^{D}\chi^2(1, 38) = 4.68$, $p<.05$; $^{E}F(1,54)=2.38$, $p=.13$

Overall, demographics analyses indicated prototypical ADHD and RD samples and supported diagnostic classifications. Groups did not differ in age. There were more boys in the ADHD-C group than in the control or pure RD groups, while the RD group had less ethnic minority representation than the Control and ADHD-C groups. Contrary to frequent findings in ADHD samples, the IQ of the ADHD children in this sample (either ADHD-C or ADHD-I) was not significantly lower than that of Control children. Likewise, the IQ's of RD children also did not significantly differ from Control or ADHD groups.

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[14] Note that 1 child not included in this table met criteria for the Hyperactive-subtype of ADHD. In addition, 5 RD children met criteria for ADHD by parent report only (i.e., "situational ADHD"), but were included in the pure RD group based upon their pattern of reading achievement, language, and learning problems (to be further described below).

Behavioral Characteristics

Detailed information regarding group differences and statistical analyses concerning behavioral indices of inattention, hyperactivity, and other externalizing and internalizing behaviors (by both maternal and teacher ratings) can be found in Appendix A (p. 171). A brief overview of these results is provided here and is summarized in Table 4.

Table 4. Inattention, Hyperactivity, ODD, and CD by group.

	Control N=27	ADHD-Only		RD-Only	RD+ADHD	
		Combined N=28	Inattentive N=7	N=13	ADHD-C N=4	ADHD-I N=3
Total Inattention* Symptoms (OR Algorithm)	0.6^{ABC} (1.0)	8.5^{AD} (0.8)	7.9^{BE} (1.1)	4.9^{CDE} (3.3)	9.0 (0.0)	8.0 (1.7)
Total Hyperactivity* Symptoms (OR Algorithm)	0.8^{AF} (1.2)	8.1^{ACD} (1.2)	3.0^{DF} (2.9)	1.2^{C} (1.4)	8.3 (1.5)	3.3 (1.2)
DISC Inattention Sympts.*	0.6 (1.0)	8.0 (1.3)	6.9 (1.7)	4.6 (3.5)	8.3 (1.0)	6.3 (2.5)
DISC Hyperactive Sympts.*	0.7 (1.1)	6.7 (2.2)	2.4 (3.2)	0.9 (1.0)	6.8 (2.2)	2.3 (0.6)
ODD (%)	$4.0^{AE G}$ (N=1)	60.7^{A} (N=17)	28.6^{E} (N=2)	30.0^{G} (N=3)	75.0 (N=3)	33.3 (N=1)
CD (%)	4.0 (N=1)	10.7 (N=3)	14.3 (N=1)	0.0 (N=0)	25.0 (N=1)	0.0 (N=0)

NOTE: Matching letters within a row are significantly different from each other.
^{A} $p<.001$; ^{B} $p<.001$; ^{C} $p<.001$; ^{D} $p<.001$; ^{E} $p<.05$; ^{F} $p<.01$; ^{G} $p<.10$, * Maximum number of symptoms=9.

As commonly found in ADHD samples, children with ADHD had higher levels of behavioral symptoms across a range of indices, including depression, anxiety, and oppositional and aggressive behavior. Also consistent with some prior studies, children with RD had higher levels of inattention, depression, and anxiety than did Control children. Findings of high levels of inattention in *both* ADHD and RD children [ADHD-

RD group interaction: $F(2,76)=10.74$, $p<.001$] provided preliminary support for behavioral phenotypic overlap between the two groups, while distinctions in terms of behavioral hyperactivity supported that these were clearly non-identical groups.

Achievement, Language, and Learning

Patterns of performance by group for reading achievement, receptive and expressive language ability (CELF-3: Concepts and Directions and Recalling Sentences subtests), and developmental and current learning problems are shown in Table 5 and briefly summarized here. More detailed description can be found in Appendix A (p. 171).

Findings here again were consistent with prior empirical findings and supported the diagnostic classifications. As expected, children with RD (regardless of comorbid ADHD status) had poorer performance across a range of achievement and language tasks and were rated by parents and teachers as having both developmental and current learning problems. Children with ADHD did not have weaknesses in basic reading skills (e.g., word recognition, phonological decoding, or spelling). However, as often found in ADHD samples, there were some indicators of achievement difficulties, particularly in reading comprehension and parent/teacher ratings of developmental and current reading/learning problems.[15] Both RD and ADHD children therefore demonstrated some form of reading achievement or learning problems, yet were readily distinguished by the RD group's greater severity and phonological decoding weakness. Note that qualitative analysis of means for the RD+ADHD children suggested that their deficits were not additive—that is, the comorbid group did not have more severe language deficits than did

[15] Thus, children with ADHD-C had poorer reading comprehension than Control children, children with ADHD-I had more developmental reading problems, and both ADHD groups were rated as having greater current learning problems than Control children.

the “pure RD” group. Overall, the preliminary sample characteristics suggested that groups were validly defined and set the stage for testing of hypotheses with the cognitive tasks.

Table 5. Achievement, Language, and Learning: Means by group.

	Control	ADHD-Only		RD-Only	RD+ADHD	
	N=27	Combined N=28	Inattentive N=7	N=13	ADHD-C N=4	ADHD-I N=3
Estimated Full Scale IQ	107.0 (16.5)	100.4 (15.4)	98.1 (13.9)	103.5 (16.0)	98.3 (8.2)	102.7 (30.1)
WIAT Reading (standard score)	104.7 (11.7) ^{E}	102.5 (13.8) ^{F}	102.4 (13.1) ^{G}	79.4 (9.2) ^{EFG}	78.0 (8.6)	86.7 (12.3)
WIAT Spelling (standard score)	102.0 (14.3) ^{E}	98.2 (15.9) ^{F}	99.9 (9.4) ^{G}	78.4 (10.3) ^{EFG}	75.0 (4.2)	75.0 (12.7)
WJ-R Word Attack (standard score)	106.6 (15.7) ^{E}	102.7 (16.7) ^{F}	97.7 (19.5) ^{A}	79.3 (10.6) ^{AEF}	82.5 (3.8)	75.5 (20.5)
WJ-R Passage Comprehension (standard score)	110.8 (17.1) ^{AE}	102.0 (13.3) ^{AD}	104.4 (15.7) ^{B}	87.2 (13.9) ^{BDE}	84.3 (7.3)	95.0 (2.8)
CELF-3 Concepts and Directions (scaled score)	10.2 (2.8)	10.1 (3.7)	10.0 (1.6)	9.5 (2.8)	8.5 (1.9)	5.0 (2.8)
CELF-3 Recalling Sentences (scaled score)	11.2 (3.0) ^{A}	10.2 (2.6) ^{C}	9.8 (3.0)	8.5 (3.3) ^{AC}	8.3 (2.2)	8.0 (5.7)
Average Achievement (Reading, Spelling, and Word Attack)	104.6 (12.4)	101.2 (14.0)	100.0 (13.1)	79.0 (9.1)	78.5 (3.5)	83.9 (15.6)
IQ-Achievement Discrepancy (SS)	2.5 (13.4)	-0.8 (14.2)	-1.9 (12.0)	24.5 (13.0)	19.8 (11.1)	18.8 (14.8)
Teacher BASC Learning Problems (T-Score)	46.2 (7.0) ^{CEF}	59.4 (9.7) ^{F}	55.7 (10.0) ^{C}	62.8 (9.5) ^{E}	69.3 (5.0)	72.0 (12.8)
Learning and Behavior Questionnaire (Total)	14.2 (7.9) ^{BE}	16.2 (7.9)	21.7 (7.8) ^{AB}	28.8 (7.5) ^{AE}	29.3 (6.3)	31.0 (6.0)
LBQ (average score: 0-5)	1.8 (1.0)	2.0 (1.0)	2.7 (1.0)	3.7 (1.0)	3.7 (0.8)	3.9 (0.8)

NOTE: Matching letters within a row are significantly different from each other.
$^{A}p<.05$; $^{B}p<.05$, $^{C}p<.07$, $^{D}p<.01$, $^{E}p<.001$, $^{F}p<.001$, $^{G}p<.001$

Ambiguous Words Task

Description of Conditions

As described in the Methods, the Ambiguous Words Task consisted of 3 primary conditions: 1) **Same** (the meaning of the ambiguous word in both the prime and target sentences was the same, less frequent/subordinate meaning), 2) **Different** (the meaning of the ambiguous word in the prime sentence was the dominant meaning and in the target sentence was the subordinate meaning), and 3) **Nonsense** (the meaning of the ambiguous word in the prime sentence had no specific meaning—i.e., the sentence had a "nonsense" meaning that didn't prime either the dominant or subordinate meaning of the word—while the target sentence contained the subordinate meaning). The following scores were then derived: **"Cost"** (i.e., interference) and **"Benefit"** (i.e., facilitation) as described below. Examples of the stimuli in each condition are shown in Table 6.

Table 6. Example Sentences and Condition Error Rates Across Groups.

	Condition	Item Example	Error Rate Vis./Aud.
Same	Prime	She threw out the pit.	15% / 20%
	Target	She spit out the pit.	13% / 14%
Different	Prime	She stole from the bank.	12% / 9%
	Target	She fished from the bank.	37% / 42%
Nonsense	Prime	She hoped the drill.	14% / 16%
	Target	She marched during the drill.	16% / 20%

Comparison of the Visual and Auditory Task

Mean accuracies across groups for the visual and auditory versions of the task as well as for the entire sample (across task versions) are reported in Table 7 (page 83). In general, the pattern of effects suggested that the experimental manipulations worked as expected for both task versions; see Tables 6 and 7). However, the tasks did appear to differ qualitatively (but not statistically significantly) in the magnitude of errors, with somewhat more errors (more interference) in the auditory version, along with lack of a RT interference effect (in contrast to the visual task). Since it was not possible to determine whether these findings were true task differences (i.e., systematic differences in the visual versus auditory task) or trends resulting from diagnostic group differences (most of the children administered the auditory task had an RD diagnosis), auditory and visual task data were analyzed separately. Due to the very small size of the group receiving the auditory task, more emphasis will be placed on visual task results.

Task Validation

Appendix A (p. 171) presents extensive background on task characteristics and validations, including an item analysis, inter-condition correlations for accuracy and RT, direct accuracy-RT correlations, age-effects (across groups) and corrections, and confirmation of basic task effects (i.e., interference effects across groups).

Overall, findings supported the effectiveness of experimental manipulations in each condition and the expected Cost (i.e., interference or inhibition) and Benefit (i.e., facilitation) effects for the visual as well as auditory versions of the Ambiguous Words Task. Accuracy data produced the clearest findings. However, RT data were also moderately supportive—especially with regard to interference effects on the visual task.

Despite the overall effectiveness of the key experimental manipulations, two minor issues and one substantial issue in the data must be noted.[16] First, diagnostic groups had different responses to the Nonsense condition. To handle this confound,

[16] For more detailed discussion of these task inconsistencies, see Appendix A (p. 190).

secondary analyses compared group differences on interference in the Different condition only (rather than relative to a Nonsense condition baseline). Second, RT "Costs," although representing *relatively* slowed responding to Different condition targets (versus other conditions), were not actually "absolute" Costs (i.e., target RT was actually *facilitated* vs. prime RT). The relevance of this finding will be addressed in the Discussion. Third, and most important, differences among conditions in prime accuracy/RT had to be statistically corrected. That issue merits more explanation here.

The issue here was that, contrary to expectations, prime accuracy and prime RT for the entire sample were <u>not</u> equivalent among the experimental conditions (Same, Nonsense, Different) (Table 7).[17] Differences among conditions on prime accuracy and RT presented a potential problem, because the relevant "Cost" and "Benefit" composite scores were initially calculated (Gernsbacher, Robertson, & Werner, 2001) from performance on *target* sentences only—in effect assuming prime sentences to be equivalent across conditions.

This issue was handled by creating "corrected" difference scores as outcome variables, in a two-step process as follows. First, an "*accuracy-corrected*" and "*RT-corrected*" score was created for each experimental condition by taking the difference between primes and targets (e.g., **"Corrected Same Accuracy"** = <u>Same **Target** Accuracy-Same **Prime** Accuracy</u>). Second, using these scores as a basis, *composite* Cost

[17] Results held when the visual task was examined in isolation, when Control children were examined in isolation [Same-Different primes: $t(1,33)=2.23$, $p<.04$], and when the auditory task was examined in isolation. The difference between Nonsense and Difference primes became statistically significant when the analysis was constrained to the performance of Control children [$t(1,33)=2.21$, $p<.04$].

and Benefit scores were calculated by combining the conditions separately for accuracy and RT data as follows[18]:

a) **Cost** (i.e., Interference) = **Nonsense (Corrected Accuracy or Corrected RT) - Different (Corrected Accuracy or Corrected RT)**

b) **Benefit** (i.e., Facilitation) = **Same (Corrected Accuracy or Corrected RT) – Nonsense (Corrected Accuracy or Corrected RT).**

The results that follow deal entirely with the Cost index, a measure of interference control or lack thereof. Because facilitation effects were not the focus here, those data and analyses can be found in Appendix B. They did not alter interpretations of the Cost variable analyses that follow. All analyses that refer to "Costs" refer to the Corrected difference scores just described.[19] **Higher** scores mean **greater** Costs or more interference.

Summary on Task Validity

Despite task inconsistencies, these problems were felt to be relatively minor with regard to overall task effects and could be accommodated by statistical corrections or post-hoc interpretations. However, given the presence of these issues compared to Gernsbacher and colleagues' (2001) findings, it seems possible that the task is measuring somewhat different processes in children than it did in their adult sample. These

[18] Note that in these composite scores the Nonsense condition serves as a theoretical "no-priming" baseline.
[19] Note that corrected accuracy Cost scores were slightly higher than those obtained when comparing accuracy for targets alone (see Table 3-5).

differences will be addressed further in the context of data interpretations in the Discussion.

Preliminary Analyses of Inhibition Effects across Groups

Preliminary analyses indicated that the experimental manipulations of interest worked as expected, producing Costs (i.e., interference/inhibition effects) in this child sample (see Table 7) that were confirmed by paired samples t-tests [Different vs. Nonsense condition: Accuracy: $t(96)=-11.12$, $p<.001$; RT: $t(82)=5.82$, $p<.001$]. The small group of children administered the auditory version of the task had a non-significantly higher accuracy Cost compared to those who received the visual version of the task [$F(1,95)=0.81$].

In Gernsbacher, Robertson, and Werner's (2001) college sample, participants incurred a 9% accuracy cost and 166 ms RT cost on this task. This contrasts with a greater than 20% accuracy cost and 700 ms RT cost in the current child sample (see Table 7). Current findings therefore suggested that interference control was far weaker in children than in adults. For the auditory task, however, RT did not reliably predict costs.[20]

[20] On the auditory task, children incurred no significant RT cost for the Nonsense compared to the Different condition [$t(1,13)=-0.10$; change=-48 ms] or from prime to target in the Different condition alone [$t(1,13)=0.95$].

Table 7. Ambiguous Words Task Means for Accuracy and Reaction Time Across Groups for Total Sample, Visual, and Auditory Task Versions.

	Same		Nonsense		Different	
	Prime	**Target**	**Prime**	**Target**	**Prime**	**Target**
Total Sample (N=97)						
Accuracy	0.84 ^{A} (0.13)	0.87 (0.13)	0.85 ^{B} (0.14)	0.83 (0.14)	0.88 ^{AB} (0.13)	0.62 (0.16)
RT	3812.00 (1222.70)	3038.70 (1127.80)	3830.80 (1450.90)	2972.50 (1016.00)	3465.90 (1196.40)	3320.80 (1187.90)
Visual (N=83)						
Accuracy	0.84 ^{E} (0.14)	0.87 (0.14)	0.86 (0.13)	0.84 (0.14)	0.88 ^{E} (0.13)	0.63 (0.17)
RT	3902.70 ^{C} (1264.80)	3039.40 (1199.00)	3940.70 ^{D} (1528.30)	3007.00 (1085.70)	3425.30 (1132.50) ^{CD}	3332.70 (1271.30)
Auditory (N=14)						
Accuracy	0.80 ^{E} (0.10)	0.86 (0.10)	0.84 (0.20)	0.80 (0.13)	0.91 ^{E} (0.09)	0.58 (0.13)
RT	3259.90 (685.20)	2995.00 (511.60)	3100.30 (364.00)	2731.40 (268.90)	3575.80 (1591.90)	3158.60 (519.50)

NOTE: Matching letters within a row are significantly different from each other. $^{A}p<.001$, $^{B}p<.10$, $^{C}p\leq.001$, $^{D}p<.001$, $^{E}p<.02$

Ambiguous Words Task: Corrected and Un-Corrected Accuracy and Reaction Time Cost Indices

	Accuracy		Reaction Time	
	Corrected	**Uncorrected**	**Corrected**	**Uncorrected**
Auditory	0.29 (.21)	0.22 (0.17)	48.4 (1779.4)	427.13 (540.49)
Visual	0.23(.21)	0.21 (0.17)	713.8 (1419.1)	349.1 (880.0)

Brief Recap of Hypotheses

Analysis now moves to specific hypothesis tests. Hypotheses involved both dimensional and categorical predictions. In brief recap of these predictions, poorer reading/language ability and higher inattention were both predicted to be related to *weaker* interference control/cognitive inhibition on the Ambiguous Words Task. Likewise, ADHD and RD children were both predicted to show poorer interference control than Control children. Note that when results refer to accuracy or RT "Costs", these costs often will be referred to as **interference**. As used here, interference is defined more broadly as indicative of relative slowing in RT or decreases in accuracy (rather than necessarily referring specifically to *competition* between two activated homonym meanings).[21]

Note about Plan of Analysis

Data for the Ambiguous Words task is hereafter analyzed in 3 parts: 1) visual task data for non-RD children (i.e,. Control and ADHD children: N=75), 2) visual task data for RD children (N=8), and 3) auditory task data for RD children (N=12). The reasons for this plan of analysis will become clearer as subsequent analyses and findings are presented. Briefly, however, in addition to findings presented above, correlational analyses revealed that patterns of results on the auditory and visual versions of the task were not equivalent. [22] To capture these differences, the data for RD children were analyzed separately on both task versions. Due to the very small sample sizes in these

[21] In other words, it would be possible for the term interference to be used to refer to a finding in which a meaning was less active (i.e., *inhibited/ less competitive*), but in which processing costs were reflected in performance. See further discussion of this interpretation in my Discussion section later.
[22] Comparisons of RD children who took the visual versus auditory tasks revealed dramatically different patterns of results on the two tasks.

comparisons, as well as the clear confounds related to administration of multiple task versions, analyses and results for RD children are necessarily viewed as preliminary..

In the results that follow, dimensional (correlational and regression) analyses are presented first, followed by analyses based on diagnostic group (ANOVA's). Regression analyses were used to determine whether indices of achievement versus inattention uniquely or additively predicted interference control/inhibitory ability (defined as Cost on the Ambiguous Words Task) when controlling for effects of other variables such as estimated IQ and age. These effects were also controlled in ANCOVA analyses.

Test of Interference Control I: ADHD/Control Comparisons

Dimensional Analyses for ADHD and Control Children on the Visual Task

Inattention, Hyperactivity, and Learning. Correlation and regression analyses examined the relationship between parent and teacher ratings of inattention, hyperactivity, learning and accuracy/reaction time Cost (Tables 8 and 9 below). Consistent with hypotheses, greater inattention was predictive of weaker interference control in terms of RT Cost across a range of indices (See Table 8).[23] Consequently, a high inattention symptom score was associated with more competition among homonym meanings and **slower** response to a context-appropriate, alternate-meaning, target. This pattern suggests failures in interference control, since successful suppression of a competing meaning should allow the context-appropriate meaning to become available more quickly. Controlling for age, IQ, and reading effects did not alter the overall pattern (Table 11, page 91). Findings for teacher ratings were particularly robust.

[23] Total inattention symptoms (by the "OR" algorithm) predicted RT Cost with marginal significance ($p<.07$, $\beta=.21$)

Table 8. Correlations for **Accuracy and RT** Cost Scores across Groups

ADHD/Control, Visual Only, N=75

	Cost (Nonsense-Different)	
	Accuracy	**Reaction Time**
Total Inattentive Symptoms‡	-.010	**.212+**
Total Hyperactivity Symptoms‡	-.008	.182
Mother-Ratings		
ARS Inattentive Raw	.040	.136
ARS Hyperactivity Raw	.058	.147
Teacher-Ratings		
ARS Inattentive Raw	.036	**.273***
ARS Hyperactivity Raw	.025	.150
BASC Attention	**.218+**	**.227***

**p<.01; * p<.05 (2-tailed); + p≤.08 (2-tailed); larger correlations=greater Costs

‡ Mother+Teacher symptoms by the "OR algorithm"

These effects failed to emerge for the accuracy Cost composite (Table 8). As a secondary check of hypotheses, correlation and regression analyses individually examined the Nonsense and Different conditions (Table 9). Supporting hypotheses of weaknesses in interference control/suppression, attention problems were a marginally significant predictor of weaker interference control in the Different [$F(1,73)=3.31$, $p<.08$, $R^2=.04$, $\beta=.21$; not robust to iq/age control] and Nonsense condition [$F(1,71)=4.05$, $p<.05$, $\Delta R^2=.05$, $\beta=.24$ after iq/age control]. Thus, indices of inattention were associated with greater interference (i.e., higher error rates/Cost) when accessing a previously context-irrelevant competing meaning of an ambiguous word (i.e., subordinate target following dominant-meaning prime). Inattention was also associated with increased cost (i.e., greater interference) to subordinate targets following *no-meaning* primes (in the Nonsense condition).

Table 9. Correlations for Prime-Target Changes in **Accuracy and RT** for Non-RD Children in the Different and Nonsense Conditions of the Visual Task (N=75)

	Different Condition Cost (Prime-Target)		**Nonsense Condition Cost (Prime-Target)**	
	Accuracy	**Reaction Time**	**Accuracy**	**Reaction Time**
Total Inattentive Symptoms‡	**.208+**	.024	**.211+**	**.216+**
Total Hyperactivity Symptoms‡	-.139	.181	.142	.044
Mother-Ratings				
ARS Inattentive Raw	**.240***	.053	.182	.111
ARS Hyperactivity Raw	**.237***	**.221+**	.158	.044
Teacher-Ratings				
ARS Inattentive Raw	.185	.105	.161	**.200+**
ARS Hyperactivity Raw	.111	.119	.064	.075
BASC Attention	**.300****	.118	.030	.150

**$p<.01$; * $p<.05$ (2-tailed); + $p\leq.08$ (2-tailed); larger correlations=greater Costs; ‡ Mother+Teacher symptoms by the "OR algorithm"

Consistent with hypotheses, then, slower RT as well as worse accuracy was associated with higher levels of inattention. Thus, despite slowing down, those with high levels of inattention still had poorer accuracy.

Secondary checks on validity of findings. To ensure that these correlational findings did not simply result from decreased task effort that could result from inattention, additional accuracy/RT correlational analyses were conducted for the individual conditions (i.e., Nonsense, Same, Different; See Table 38, p. 191, in Appendix A for the relevant correlations and inattention indices). Analyses revealed significant correlations between *accuracy* and indices of inattention for both primes and targets across most conditions (r's from -.26 to -.40), but no significant correlations with *RT*.

The dissociation between accuracy and RT correlations with inattention suggested that children with high levels of inattention had more difficulty with this task as a whole, but that these difficulties were ***not*** associated with impulsive responding or decreased effort. Such an interpretation was supported by failure to find significant correlations (or even close to significant correlations) between inattention and RT on global task performance—i.e., when including RT on *incorrect* as well as *correct* responses.

Consistent with the validity of the primary hypothesis test, then, these secondary checks suggested that findings related to inattention on this task represent valid cognitive impairments rather than artifacts of speed-accuracy trade-offs or decreased task effort.[24] Note also that accuracy findings were always reported as *relative* differences (i.e., *change* from prime to target), so that globally poorer accuracy differences should not affect interpretability of findings.

Achievement and Language. Correlations and regressions for measures of achievement, IQ, language and accuracy/RT Cost (i.e., interference) are shown in Tables 10 and 11. Contrary to hypotheses, reading achievement was not related to interference in lexical ambiguity resolution (as measured by either accuracy or RT Cost or individually for the Different and Nonsense conditions) for these non-reading impaired children. Thus, across ADHD and Control groups, for those receiving the visual version of the task (N=75), correlations between measures of reading achievement and accuracy or RT Cost (i.e., magnitude of interference) were all non-significant (See Table 10).

Findings were robust to age and IQ controls (Table 11 and 12, p. 91-92). However, regression analyses revealed a marginally significant interaction between mean reading achievement and inattention symptoms (with IQ controlled; $F(1,70)=3.58$, $p=.06$; $R^2\Delta=.04$), such that better reading ability was associated with *more* interference/higher

---

[24] One exception to this finding was a significant correlation between hyperactivity and both **prime** accuracy ($r=-.24$, $p=.04$) and RT ($r=-.41$, $p<.02$) in the Same condition (i.e., subordinate prime) as well as hyperactivity and **target** accuracy ($r=-.28$, $p<.02$) and **target** RT ($r=-.42$, $p<.02$). Thus, it is possible that impulsive responding and decreased effort contributed to poorer performance when primes were subordinate-meaning homonyms, but these findings are not relevant to hypotheses regarding interference control (although they would be applicable to questions regarding facilitation effects—not the current focus).

accuracy Cost (Mean Reading Score: r=.38, p<.10; Word Reading: r=.39, p<.05) in Control children but *less* interference in ADHD children (-.28, p=.12). This finding thus suggests that inattention may moderate the relationship between reading and interference control.

Table 10. IQ, Achievement, and Language Correlations for **Accuracy** and **RT** Cost across Non-RD Groups on the Visual Task (N=75).

	Accuracy Cost	**Reaction Time Cost**
Age	.060	.134
Full Scale IQ (Estimated)	**-.277****	.030
Nonverbal IQ (Estimated)	**-.277****	.002
Mean Reading Score	-.026	.104
Passage Comprehension (SS)	-.149	.009
Concepts and Directions (ss)	.049	.021
Recalling Sentences (ss)	**-.238***	.097

*p<.05 (2-tailed); ** p<.02 (2-tailed); + p<.10 (2-tailed)

Working Memory and IQ. In children without reading impairments, better working memory capacity and higher intelligence were associated with better interference control, i.e., with more success in selecting context-appropriate meanings of homonyms.[25] These effects provided encouraging validation of the tasks as measures of the relevant higher-order interference control construct intended. Given findings in the empirical literature concerning the relationship between working memory capacity and reading comprehension ability, this finding was of particular interest.

Specifically, weaker expressive language/working memory (on the Recalling Sentences test) was associated with greater interference (i.e., larger accuracy Cost but *not*

[25] If intelligence is thought of as relating in some respects to information processing capacity and efficiency, this finding for intelligence seems appropriate. The empirical literature also indicates that working memory capacity is an important factor in reading comprehension (to be discussed later in more detail).

RT Cost). Conversely, then, larger working memory capacity was predictive of reduced interference from competing homonym meanings.[26] Although this effect was no longer significant after controlling for IQ, IQ accounted for only approximately half of this variable's effect (β= .12 after IQ controlled; IQ-Recalling Sentences correlation: r=.58, p<.001; Table 12, pg. 92).[27] RT was not related to interference control on this measure.

Summary. Key findings from dimensional analyses can be summarized as follows: 1) Higher inattentive (but not hyperactive) ADHD symptom score was associated with more interference (support of hypothesis); 2) Reading achievement was related to interference only after accounting for the moderating relationship of attention (variation on hypothesis or partial support); 3) Smaller working memory capacity (or weaker expressive language) was associated with more interference (support of hypothesis).

[26] Note that total inattention symptoms was not significantly correlated with performance of Recalling Sentences (r=-.06), suggesting that working memory capacity and inattention are independent predictors or interference control.

[27] In addition, while reading achievement and Recalling Sentences performance were moderately correlated (r=.43, p<.001), controlling for reading ability did not influence this test's predictive power (see Table 12, pg 92), providing further indication that performance on the Recalling Sentences test may depend on factors in addition to language ability (i.e., working memory capacity) and that these independent factors, not language ability per se—e.g., working memory capacity-- might account for the prediction of interference control with this measure.

Table 11. RT Cost Regressions for ADHD and Control Children on the Visual Ambiguous Words Task (N=75)

	Variable	R^2	Adj. R^2	ΔR^2	F for $R^2\Delta$	$\beta^{\dagger}$	T
1	**Mean Achievement**	.01	-.00	.01	0.79 (1,73)	.10	0.89
2							
Step 1	**Full Scale IQ (estimated)**	.00	-.01	.00	0.07 (1,73)	-.11	-0.83
Step 2	**Age (Months)**	.02	-.01	.02	1.54 (1,72)	-.12	-0.92
Step 3	**Mean Achievement**	.03	-.01	.01	0.66 (1,71)	.12	0.81
1	**Total Inattention Sympts.**	**.05**	**.03**	**.05**	**3.44 (1,73)$^{+}$**	**.21**	**1.85^{+}**
2							
Step 1	**Full Scale IQ (estimated)**	.00	-.01	.00	0.07 (1,73)	-.03	-0.26
Step 2	**Age (months)**	.02	-.01	.02	1.54 (1,72)	-.11	-0.95
Step 3	**Total Inattention Sympts.**	.06	.02	.04	2.65 (1,71)	.19	1.63
1	**Teacher Inattention (TARS)**	**.07**	**.06**	**.07**	**5.86 (1,73)***	**.27**	**2.42***
2							
Step 1	**Full Scale IQ**	.00	-.01	.00	0.07 (1,73)	.01	0.08
Step 2	**Age**	.02	-.01	.02	1.54 (1,72)	-.10	-0.85
Step 3	**Teacher Inattention (TARS)**	**.09**	**.05**	**.06**	**4.90 (1,71)***	**.26**	**2.21***
1							
Step 1	**Mean Achievement**	.06	.02	.06	1.61 (3,71)	.15	1.13
	Total Inattention Sympts.					**.22**	1.90^{+}
	Full Scale IQ (estimated)					-.07	-0.50
Step 2	**Interaction (Achiev.*Inatt.)**	.07	.02	.01	0.73 (1,70)	.10	0.85

$^{\ddagger}\beta$ after final step; **$p \leq .001$; *$p \leq .05$; + $p \leq .08$; positive β's=larger Costs.

Table 12. Accuracy Cost Regressions for ADHD and Control Children on the Visual Ambiguous Words Task (N=75)

	Variable	R^2	Adj. R^2	ΔR^2	F For $R^2 \Delta$	$\beta^{\ddagger}$	T
1	**Mean Achievement**	.00	-.01	.00	0.05 (1,73)	-.03	-0.22
2							
Step 1	**Full Scale IQ (estimated)**	.08	.06	.08	6.04 (1,73)*	-.34	-2.66**
Step 2	**Age (Months)**	.08	.05	.00	0.00 (1,72)	.04	0.36
Step 3	**Mean Achievement**	.09	.06	.02	1.35 (1,71)	.16	1.16
1	**Total Inattention Symptoms**	.00	-.01	.00	0.01 (1,73)	-.01	-0.09
2							
Step 1	**Full Scale IQ (estimated)**	.08	.06	.08	6.04 (1,73)*	-.29	-2.41*
Step 2	**Age (Months)**	.08	.05	.00	0.00 (1,72)	-.01	-0.08
Step 3	**Total Inattention Symptoms**	.08	.04	.00	0.17 (1,71)	-.05	-0.42
1							
Step 1	**Mean Achievement**	**.09**	**.06**	**.09**	**2.50 (3,71)+**	**.16**	**1.25**
	Total Inattention Symptoms					**-.07**	**0.57**
	Full Scale IQ (estimated)					**-.38**	**-2.95****
Step 2	**Interaction (Achiev.*Inatt.)**	**.14**	**.09**	**.04**	**3.58 (1,70)+**	**-.21**	**-1.89+**
1	**Recalling Sentences**	**.06**	**.04**	**.06**	**4.40 (1,73)***	**-.24**	**-2.10***
2							
Step 2	**Full Scale IQ**	.09	.06	.01	0.73 (1,72)	-.21	-1.51
	Recalling Sentences					-.12	-0.86
3							
Step 2	**Mean Achievement**	**.06**	**.04**	**.06**	**4.87 (1,72)***	**.09**	**0.74**
	Recalling Sentences					**-.28**	**-2.21***

‡ β after final step in the model; ** p≤ .01; *p<.05; + p≤.07

Categorical Analyses for ADHD and Control Children on the Visual Task

To evaluate hypotheses regarding group differences (apart from dimensional associations on the variables of interest) a limited number of analyses of variance were performed. ANOVA's combined ADHD-C and ADHD-I children into a single group (because most correlation and regression results were related to inattention and the inattentive-only group was small) and compared this group to a group of Control children.[28]

[28] Findings were checked for the ADHD-C group when ADHD-I children were excluded and results remained unchanged in all cases.

Accuracy. The 2 (Group: ADHD vs. Control) x 2 (Sex: Boys vs. Girls) ANOVA for accuracy Cost was significant [$F(1,55)=9.25$, $p=.004$, $\eta^2=.144$; Figure 1], such that girls with ADHD demonstrated much more interference (higher Costs) from competing homonym meanings [mean: 0.46 ± 0.18; $F(1,23)=9.25$, $p=.006$, $\eta^2=.287$] than ADHD boys (mean: 0.18 ± 0.18) or Control girls or boys (means: 0.24 ± 0.17 and 0.26 ± 0.17, respectively). This effect was robust to age and IQ covariance and also held when performance was examined in the Different condition alone [$F(1,55)=12.14$, $p=.001$, $\eta^2=.18$].

Figure 1. Group by Sex Interaction for Accuracy Cost in ADHD vs. Control

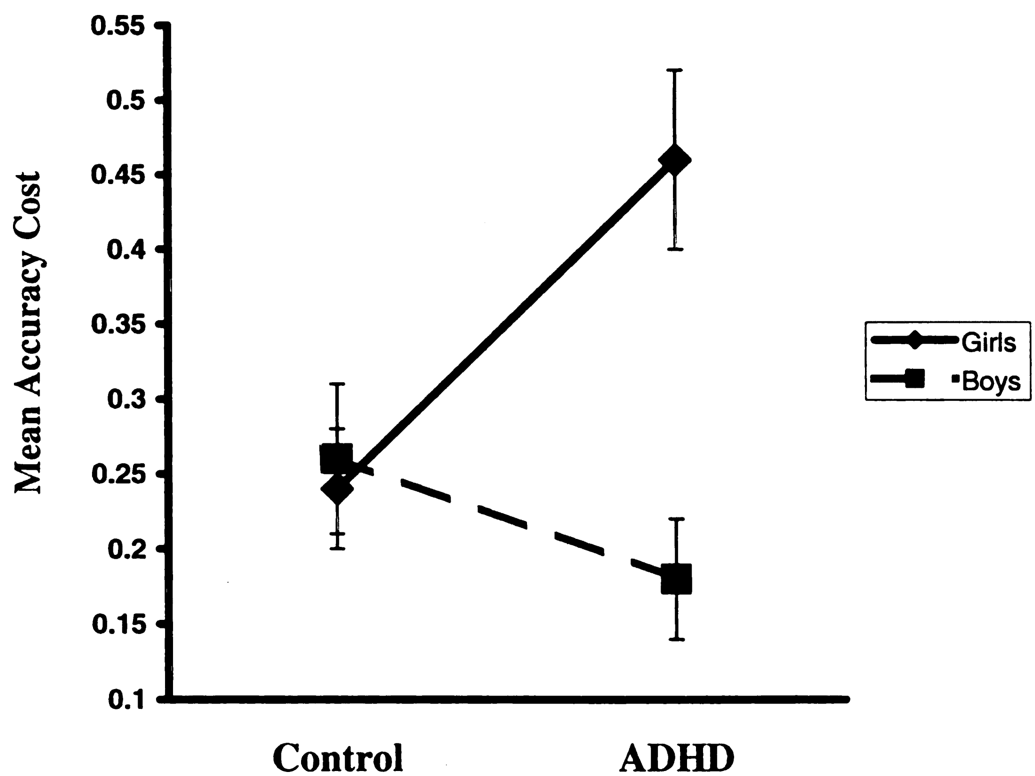


Table 13. Group Means for Accuracy and RT on the Visual Ambiguous Words Task

		Control	ADHD-C + ADHD-I	ADHD-Only ADHD-C	ADHD-Only ADHD-I
Accuracy					
Same					
	Prime	0.91 (0.1)	0.80 (0.2)	0.82 (0.2)	0.74 (0.2)
	Target	0.95 (0.1)	0.82 (0.1)	0.82 (0.1)	0.80 (0.1)
Nonsense					
	Prime	0.85 (0.2)	0.86 (0.1)	0.87 (0.1)	0.83 (0.1)
	Target	0.89 (0.1)	0.82 (0.1)	0.81 (0.2)	0.82 (0.1)
Different					
	Prime	0.93 (0.1)	0.87 (0.2)	0.85 (0.2)	0.92 (0.1)
	Target	0.73 (0.1)	0.57 (0.2)	0.56 (0.2)	0.61 (0.2)
Filler					
	Prime	0.92 (0.1)	0.88 (0.1)	0.87 (0.1)	0.89 (0.1)
	Target	0.89 (0.1)	0.85 (0.1)	0.84 (0.1)	0.90 (0.1)
Reaction Time					
Same					
	Prime	3601.0 (1018.2)	4075.0 (1368.5)	3982.7 (1339.9)	4417.8 (1527.6)
	Target	2659.9 (812.0)	3189.9 (1248.6)	2940.5 (966.0)	4116.1 (1776.6)
Nonsense					
	Prime	3986.5 (1396.9)	3810.6 (1225.8)	3829.1 (1299.6)	3742.0 (984.6)
	Target	2769.6 (911.8)	3135.4 (1161.0)	3038.9 (1049.8)	3493.7 (1551.6)
Different					
	Prime	3377.2 (1196.0)	3512.8 (1226.4)	3563.4 (1328.0)	3375.0 (958.7)
	Target	3074.0 (786.3)	3338.4 (1233.2)	3255.7 (1157.3)	3697.9 (1593.9)
Filler					
	Prime	3610.0 (1007.6)	3769.8 (1096.9)	3747.3 (1065.1)	3853.6 (1296.1)
	Target	3191.4 (959.9)	3221.3 (1016.5)	3192.3 (969.7)	3329.1 (1255.1)

Interference Scores

	Control	ADHD-C + ADHD-I	ADHD-Only ADHD-C	ADHD-Only ADHD-I
Cost (Corrected) (Different – Nonsense)				
Accuracy	0.25 (0.17)	0.25 (0.22)	0.24 (0.22)	0.30 (0.21)
Reaction Time	898.9 (760.7)	500.9 (1086.1)	481.9 (1217.7)	571.1 (325.3)

*Reaction Time.*_ To examine the effect of interference on reaction time, an additional 2 x 2 (Group x Sex) ANOVA examined group differences in RT Cost. The group by sex interaction was not significant [F(1,55)=0.12]. Since there were no sex differences, data for girls and boys were combined and an additional univariate ANOVA examined RT Cost across sex. This analysis revealed a marginally significant group main effect [F(1,58)=2.59, p=.11] that was weakened by age and IQ covariance.

Secondary comparisons of RT changes from prime to target in the Nonsense condition for Control versus ADHD children was significant [F(1,58)=5.29, p=.03, η^2=.08], such that ADHD children showed smaller reductions in RT from prime to target (i.e., increased interference/Cost) than did Control children. In contrast, the test of prime-target RT differences in the Different condition was non-significant [F(1,58)=0.35] indicating no differences in relative change in RT between groups (i.e., no interference differences).

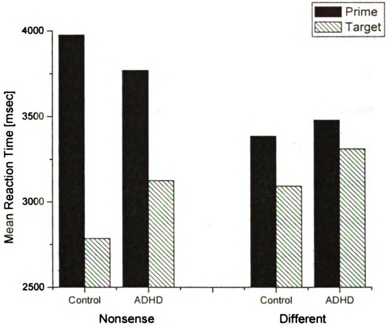
Contrary to accuracy findings, then, comparisons of RT changes for ADHD and Control children suggested that primary differences in interference control occurred when a subordinate target followed a no-meaning prime (i.e., Nonsense condition), whereas both groups experienced similar slowings of RT (and thus similar interference as measured in RT) to subordinate targets following a dominant-meaning prime (i.e., Different condition).[29]

Summary of Categorical Analyses. Comparisons of ADHD and Control groups revealed a sex-specific impairment in interference control for girls with ADHD in terms

[29] It should be recalled (as mentioned earlier) that *all* subjects experienced *facilitation* in RT (i.e. got faster) from prime to target. Thus, "costs" in reaction time actually reflect differences in relative RT benefit between prime and target and findings could instead be interpreted as reflecting activation failures.

of accuracy Cost. All children with ADHD also had relatively slower response times to targets following a no-meaning netural prime; (i.e., Noensense condition) that provided some, albeit weaker, support for the hypothesis.

Figure 2. Comparison of Prime-Target RT Differences in the Nonsense vs. Different Conditions



Summary of Key Findings for ADHD and Control Children on the Visual Task

Overall, consistent with predictions, both high levels of inattention and ADHD diagnosis were associated with more interference from competing homonym meanings, consistent with weakness in inhibition mechanisms that protect language comprehension. Secondly, somewhat differently than predicted, inattention influenced the relationship between reading and interference control such that high levels of inattention attenuated the association between reading ability and interference. Finally, smaller working memory capacity was also associated with weaker interference control.

Test of Inhibition Effect II: RD Comparisons for the Visual versus Auditory Tasks

Dimensional Analyses for RD Children on the Visual versus Auditory Task[30]

For children with RD, correlation and regression analyses were conducted separately for subjects receiving the visual and auditory versions of the task (for reasons explained earlier). Although this sample was quite small (making the power to detect statistical differences low), it is notable that the correlations between task performance and measures of reading achievement and inattention/hyperactivity were in *opposite* directions for children administered the visual versus auditory versions of the tasks. Important for interpreting the results that follow is that children taking the visual version of the task were higher functioning with regard to reading performance (thus they read well enough to take the visual task) than children taking the auditory version of the task.

Achievement and Language. For RD children who took the auditory task (due to low reading ability), mean reading achievement (word recognition, spelling, and phonological decoding) significantly predicted accuracy Cost, such that higher achievement was associated with decreased interference from competing homonym meanings (Table 14, p. 98).[31] This finding was not robust to IQ and age control but the effect was still quite strong ($\Delta R^2=.20$, $\beta=-.59$).[32] There was no effect for RT.

In contrast, for RD children on the visual task (N=8), lower reading achievement and history of more severe developmental reading problems were associated with *less*

[30] Group means are in Table 22, pg. 107

[31] Note, however, that these scores likely have a very truncated range because reading achievement for all of these RD children was very low.

[32] Paradoxically, higher teacher-rated learning problems also marginally significantly predicted reduced interference after age and IQ were controlled ($\Delta R^2=.25$). However, learning problems appeared to be more related in all analyses to inattention and this finding would be consistent with those results.

interference (lower accuracy costs; see Table 14)—or, conversely, higher reading achievement was associated with *greater* interference (higher accuracy costs or increased competition between alternate meanings of ambiguous words) for accuracy but not for RT.[33] Poorer reading performance in these "functional" RD readers may thus be suggestive of interference control problems, manifested by normal activation of homonym meanings but failure to constrain access to the context-appropriate meaning. Age and IQ did not significantly affect this relationship.

Table 14. Achievement/IQ Correlations for Accuracy and RT **Cost** Scores for RD Children on Visual and Auditory Tasks

	VISUAL (N=8)		**AUDITORY (N=12)**	
	Accuracy	**Reaction Time**	**Accuracy**	**Reaction Time**
Age	-.275	**.636+**	.424	.142
Full Scale IQ (Estimated)	.391	-.588	-.274	.424
Nonverbal IQ (Estimated)	.404	-.423	-.045	.444
Mean Reading Score	**.635+**	-.378	**-.615***	.055
Passage Comprehension (SS)	.575	-.076	**-.878****	-.084
WIAT Reading (SS)	**.765****	-.332	**-.582***	-.022
Concepts and Directions (ss)	.087	-.348	-.275	.002
Recalling Sentences (ss)	.108	-.053	**-.649***	.440

** p<.02 (2-tailed); * p<.05 (2-tailed); + p<.10 (2-tailed); larger correlations=larger costs

Working Memory and IQ. On the auditory task, as found in the ADHD/Control group, weaker expressive language/ working memory but not receptive language was associated with greater interference (r=-.65) in accuracy. Thus, as expected by the empirical literature on lexical ambiguity resolution, larger working memory capacity was predictive of reduced interference from competing homonym meanings, even after controlling for age and IQ (Table 18, pg. 101). This effect also remained marginally significant above and beyond the effect predicted by reading achievement ($R^2\Delta$ =.18; β=-

[33] There was, however, a marginally significant association between older age and *increased* interference (RT Cost: r=.64).

.47).[34] The model incorporating reading achievement, inattention symptoms, and expressive language/working memory was a statistically significant predictor of interference, with higher working memory/reading abilities and inattention all predicting reduced interference [$F(3,8)=4.17$, $p<.05$; $R^2=.61$].

In contrast, on the visual task, performance on the expressive language/working memory measure (Recalling Sentences) did not predict interference (for accuracy or RT). Controlling IQ and reading achievement did not affect this finding. Thus, one possibility is that expressive language or working memory deficits are an additional (i.e., independent) factor that independently affects the functioning of children with RD, such that children who have this deficit are more severely affected than those who do not (thereby explaining the findings for RD children on the auditory task); alternatively, poorer working memory capacity (and, consequently, poorer interference control) could be a byproduct of a more severe RD impairment.

Inattention, Hyperactivity, and Learning. Correlations between Cost scores (i.e., interference) and symptoms of parent and teacher-rated inattention and hyperactivity for children with RD on the visual versus auditory tasks are shown in Table 15.

For RD children who took the auditory task, inattention/hyperactivity was not associated with accuracy Cost, even after controlling for age and IQ effects. There was, however, a significant correlation between mother-rated attention problems on the BASC and RT Cost, such that high levels of inattention were associated with reduced interference ($r=-.61$). This finding was not robust across multiple attention indices.

[34] Thus, as with findings for Control/ADHD children, this finding provides further indication that performance on the Recalling Sentences test may depend on factors in addition to language ability (i.e., working memory capacity) and that these independent factors, not language ability per se might account for the prediction of interference control with this measure.

Reading and total inattention symptoms did not interact to predict interference (i.e., Cost) on the auditory task (Table 18). However, the interaction of inattention and age was a marginally significant predictor of accuracy Cost, such that older children *with* attention problems experienced *less* interference from competing homonym meanings than those *without* attention problems. Both groups had higher levels of interference than younger RD children, for whom inattention did not affect level of interference. This finding suggests that lower functioning children with RD (i.e., those who could not read well enough to take the visual task) experience increased interference with age, but that inattention moderates and attenuates this effect. High levels of inattention may thus interfere with a developmental trajectory for maturation of inhibitory mechanisms that constrain activation to the context-appropriate meaning of the ambiguous word.

On the visual task, greater mother-rated inattention was associated with a pattern of higher RT Cost (i.e., greater interference) across multiple indices. Again reciprocal to findings for the auditory task, symptoms of inattention significantly positively predicted RT Cost when age was controlled ($R^2 = .76$, $R^2\Delta = .36$, $p \leq .05$; Table 17), such that increased inattention was associated with increased interference in high functioning RD children. The strong positive predictive power of age on RT Cost suggests that interference increased with age independently of inattention effects.[35] Accuracy Cost was not correlated with any indices of inattention or hyperactivity, and there was no interaction between reading achievement and inattention in predicting interference control for either accuracy or RT.

[35] *Note that this finding matched that for the auditory task,* paradoxically reflecting the development of inhibitory mechanisms that ultimately constrain activation to the context-appropriate meaning of the ambiguous word as children age.

Table 15. Inattention and Hyperactivity Correlations for **Accuracy** Cost for RD children on the Visual and Auditory Task

	VISUAL (N=8)		AUDITORY (N=12)	
	Accuracy	**Reaction Time**	**Accuracy**	**Reaction Time**
Total Inattentive Symptoms	-.249	.401	-.032	.450
Total Hyperactivity Symptoms	.096	.281	-.248	-.036
Mother				
ARS Total (Raw)	-.116	.576	-.070	.015
ARS Inattentive (Raw)	-.156	**.627+**	-.070	-.072
ARS Hyperactivity (Raw)	-.033	.421	-.066	.092
BASC Attention (T-Score)	-.188	.466	-.158	**-.607***
Teacher				
ARS Total (Raw)	.375	.065	-.178	-.083
ARS Inattentive (Raw)	.173	.154	-.268	-.014
ARS Hyperactivity (Raw)	.594	.064	-.050	-.125
BASC Attention (T-Score)	.398	.369	-.358	-.247
BASC Learning (T-Score)	-.092	.283	-.456	.008

+ p<.08 (2-tailed)

Conclusions. For all RD children, reading ability was associated with level of interference, although the pattern of findings differed for the visual versus auditory tasks. RD children administered the auditory task demonstrated *more* interference as a function of both weaker reading and smaller working memory capacity, whereas RD children on the visual task showed an association between lower reading achievement and *less* interference (or stronger reading ability and *more* interference). For both groups, data are consistent with the idea that higher levels of inattention disrupt a developmental trajectory towards more constraint-based lexical access that could be associated with development of inhibition-driven ambiguity resolution (and, consequently, with an attention-related inhibition deficit).

Table 16. Accuracy Cost Regressions for the Visual Ambiguous Words Task: RD (N=8)

Model	Variable	R^2	Adj. R^2	ΔR^2	F $R^2\Delta$	$\beta^‡$	T
1	**Mean Achievement**	**.40**	**.30**	**.40**	**4.05 (1,6)+**	**.63**	**2.01+**
2	**Full Scale IQ (estimated)**	.41	.17	.25	2.12 (1,5)	-.06	-0.14
	Mean Achievement					**.68**	1.46
3	**Age (Months)**	.45	.23	.37	3.36 (1,5)	**-.21**	-0.63
	Mean Achievement					**.61**	1.83
1	**Total Inattention Symptoms**	.06	-.10	.06	0.40 (1,6)	-.25	-0.63
2	**Full Scale IQ (estimated)**	.16	-.18	.01	0.04 (1,5)	**.35**	0.76
	Total Inattention Symptoms					-.09	-0.19
3	**Age (months)**	.19	-.14	.11	0.70 (1,5)	-.37	-0.89
	Total Inattention Symptoms					-.35	-0.84
1							
Step 1	**Mean Achievement**	.41	.17	.41	1.71 (2,5)	**.70**	1.69
	Total Inattention Symptoms					-.08	0.85
Step 2	**Interaction (Achiev.*Inatt.)**	.45	.04	.05	0.33 (1,4)	.23	0.59
1	**Recalling Sentences**	.01	-.15	.01	0.07 (1,6)	.11	0.27
2	**Age (months)**	.12	-.23	.05	0.28 (1,5)	-.36	-0.80
	Recalling Sentences					.24	0.53

‡β after final step; +p≤.10

Table 17. RT Cost Regressions for the Visual Ambiguous Words Task: RD (N=8)

Model	Variable	R^2	Adj. R^2	ΔR^2	F $R^2\Delta$	$\beta^‡$	T
1	**Mean Achievement**	.14	.00	.14	1.00 (1,6)	**-.38**	-1.00
1	**Total Inattention Symptoms**	.16	.02	.16	1.15 (1,6)	**.40**	1.07
2	**Full Scale IQ (estimated)**	.37	.11	.02	0.17 (1,5)	**-.51**	-1.28
	Total Inattention Symptoms					.16	0.41
3	**Age (months)**	**.76**	**.67**	**.36**	**7.46 (1,5)***	**.81**	**3.55***
	Total Inattention Symptoms					**.62**	**2.73***
1	**Mother Inattent Sxs. (MARS)**	**.39**	**.29**	**.39**	**3.89 (1,6)+**	**.63**	**1.97+**
2	**Age (months)**	**.85**	**.79**	**.45**	**15.24 (1,5)***	**.68**	**3.95***
	Mother Inattent Sxs. (MARS)					**.67**	**3.90***
1							
Step 1	**Mean Achievement**	.23	-.08	.23	0.75 (2,5)	**-.46**	-1.10
	Total Inattention Symptoms					**.37**	0.93
Step 2	**Interaction (Achiev.*Inatt.)**	.44	.03	.21	1.52 (1,4)	**-.50**	-1.23

‡β after final step; *p ≤ .05; +p≤.10; positive β's=larger Costs.

Table 18. Accuracy Cost Regressions for Auditory Ambiguous Words Task (N=12)

Model	Variable	R^2	Adj. R^2	ΔR^2	F $R^2\Delta$	β‡	T
1	**Mean Achievement**	**.38**	**.32**	**.38**	**6.10 (1,10)***	**-.62**	**-2.47***
2							
Step 1	Full Scale IQ (estimated)	.08	-.02	.08	0.81 (1,10)	.09	0.28
Step 2	Age (Months)	.19	.01	.12	1.29 (1,9)	.13	0.40
Step 3	Mean Achievement	.39	.17	.20	2.69 (1,8)	-.59	-1.64
1	Total Inattention Symptoms	.00	-.10	.00	0.01 (1,10)	-.03	-0.10
2	Full Scale IQ (estimated)	.22	-.08	.03	0.34 (1,8)	-.12	-0.36
	Age (months)					.43	1.21
	Total Inattention Symptoms					-.19	-0.59
1	**Age**	**.48**	**.29**	**.27**	**4.14 (1,8)+**	**.62**	**2.24+**
	Total Inattention Symptoms					**-.37**	**-1.29**
	Interaction (Age*Inattention)					**-.55**	**-2.03+**
1							
Step 1	**Mean Achievement**	**.41**	**.28**	**.41**	**3.15 (2,9)+**	**-.79**	**-2.95***
	Total Inattention Symptoms					-.28	-1.08
Step 2	Interaction (Achiev.*Inatt.)	.53	.35	.11	1.92 (1,8)	.37	1.39
1	**Recalling Sentences**	**.42**	**.36**	**.42**	**7.27 (1,10)***	**-.65**	**-2.70***
2	**Full Scale IQ**	**.56**	**.40**	**.37**	**6.86 (1,8)***	**.43**	**1.31**
	Age (months)					**.34**	**1.30**
	Recalling Sentences					**-.83**	**-2.62***
3	**Mean Achievement**	**.61**	**.46**	**.61**	**4.17 (3,8)***	**-.46**	**-1.86+**
	Recalling Sentences					**-.49**	**-2.02+**
	Inattention					**-.22**	**-0.98**

‡β after final step; †p ≤ .001; **p≤.01; *p≤ .05; + p≤.10

Table 19. RT Cost Regressions for Auditory Ambiguous Words Task (N=12)

Model	Variable	R^2	Adj. R^2	ΔR^2	F $R^2\Delta$	β‡	T
1	Mean Achievement	.06	-.10	.00	0.03 (1,10)	.06	0.18
2							
Step 1	Full Scale IQ (estimated)	.16	-.15	.00	0.00 (1,8)	.41	1.06
Step 2	Age (Months)					.33	0.83
Step 3	Mean Achievement					.02	0.06
1	Total Inattention Symptoms	.20	.12	.20	2.54 (1,10)	-.45	-1.59
2	**Full Scale IQ (estimated)**	**.42**	**.20**	**.26**	**3.51 (1,8)+**	**.39**	**1.31**
	Age (months)					**.48**	**1.55**
	Total Inattention Symptoms					**-.53**	**-1.87+**
Step 2	Interaction (Achiev.*Inatt.)	.34	-.03	.07	0.71 (1,7)	.31	0.84
2							
Step 1	Mean Achievement	.31	.05	.31	1.19 (3,8)	.00	0.01
	Total Inattention Symptoms					-.61	-1.89+
	Age (months)					.32	0.85
Step 2	Interaction (Achiev.*Inatt.)	.39	.04	.08	0.91 (1,7)	.31	0.95

‡β after final step; +p≤.10; positive β's=larger Costs.

Secondary Comparison of Current Findings to those of

Gernsbacher, Robertson, and Werner (2001)

In addition to experimental hypotheses, an additional question of interest was how the current findings in this child sample compared to those of Gernsbacher and colleagues' college sample of poor versus good comprehenders, and whether current findings supported a relationship between inhibitory deficits and reading comprehension. The relationship between passage comprehension and accuracy/RT Cost was therefore examined separately for the auditory and visual tasks.

On the auditory task, passage comprehension significantly negatively predicted accuracy Cost above and beyond effects of overall reading achievement, IQ, and age (Table 54, below). Thus, higher reading comprehension was associated with reduced interference (i.e., decreased Cost).[36] Together, reading achievement and passage comprehension explained 82% of the variance in interference control, with passage comprehension accounting for the majority of this effect ($\beta_{comprehension}$= -.76 vs. $\beta_{reading}$ = -.23).

To further explore how well interference control (i.e., Cost) *predicted* reading comprehension above and beyond reading ability, Cost and reading achievement were entered as predictors in a regression with passage comprehension as the *outcome*. This analysis revealed that interference control accounted for the vast majority of predictive

[36] Note that in Gernsbacher et al's study, decreased Cost was taken as a reflection of inhibition *failures* (which, according to Gernsbacher's Structure Building Framework, should produce poorer comprehension). As a result, if interpreted according to Gernsbacher et al's schema, the current findings would actually suggest that better reading comprehension predicted an inhibition *deficit*. An alternative interpretation of this finding will be reviewed in the Discussion.

power for passage comprehension performance (β_{Cost}= -.91 vs. $\beta_{reading}$ = -.05)[37], such that—consistent with Gernsbacher's hypothesis—poorer interference control (increased Cost) was associated with poorer reading comprehension. In interpreting these findings, it is important to note that given the very low reading abilities of children in this group, the range of performances on this task was truncated. Despite the supportive findings for accuracy results, passage comprehension was not associated with RT interference (contrary to Gernsbacher's findings).

Table 20 Auditory Task

Model	Variable	R^2	Adj. R^2	ΔR^2	F $R^2\Delta$	$\beta^{‡}$	T
1	**Passage Comprehension**	.77	.75	.77	**33.53 (1,10)†**	**-.88**	**-5.79†**
2	**Full Scale IQ**	.79	.71	.60	**22.45 (1,8)†**	**-.13**	**-0.75**
	Age					-.12	-0.56
	Passage Comprehension					**-.91**	**-4.74†**
3	**Mean Achievement**	**.81**	.77	**.43**	**20.24 (1,9)†**	**-.23**	**-1.35**
	Passage Comprehension					**-.76**	**-4.50†**
4	**DV=Passage Comprehension**						
Step 1	**Mean Achievement**	.26	.19	.26	**3.49 (1,10)+**	**.51**	**1.87+**
Step 2	**Mean Achievement**	.77	.72	.51	**20.24 (1,9)†**	**-.05**	**-0.25**
	Accuracy Cost					**-.91**	**-4.50†**

On the visual task, similar to other differences in auditory versus visual task performance, there was a trend towards a *positive* predictive relationship between passage comprehension and accuracy Cost, such that poorer reading comprehension in this group was associated with reduced interference. Thus, one possibility that would be consistent with Gernsbacher's theory is that these individuals have poorer interference control or an inhibitory deficit (i.e., "less cost"). It is notable, however, that this effect was largely

[37] Accuracy cost accounted for 50% more variance than reading ability in predicting performance.

accounted for by overall reading achievement (see Table 55, below) and the two constructs were highly related (r=.88, p<.01) in this group. Changes in response speed (i.e., RT Cost) were not predicted by Passage Comprehension performance in this group.

Table 21 Visual Task

Model	**Variable**	**R^2**	**Adj. R^2**	**ΔR^2**	**F $R^2\Delta$**	**$\beta^{\ddagger}$**	**T**
1	**Passage Comprehension**	.33	.22	.33	2.96 (1,6)	.56	1.72
2	**Full Scale IQ**	.33	.06	.18	1.33 (1,5)	.02	0.04
	Passage Comprehension					.56	1.15
3	**Age**	.47	.25	.39	3.68 (1,5)	-.38	-1.13
	Passage Comprehension					.63	1.92
4	**Mean Achievement**	.40	.17	.00	0.01 (1,5)	.57	0.79
	Passage Comprehension					.07	0.10

Table 22. RD Group Means for the Auditory and Visual Versions of the Ambiguous Words Task

		AUDITORY			VISUAL		
			RD+ADHD			RD+ADHD	
		RD-Only N=8	ADHD-C N=2	ADHD-I N=2	RD-Only N=5	ADHD-C N=2	ADHD-I N=1
Accuracy							
Same							
	Prime	0.78 (0.1)	0.88 (0.1)	0.75 (0.1)	0.73 (0.1)	0.71 (0.2)	0.92
	Target	0.88 (0.1)	0.88 (0.2)	0.88 (0.2)	0.68 (0.2)	0.75 (0.2)	0.92
Nonsense							
	Prime	0.87 (0.2)	0.96 (0.1)	0.85 (0.1)	0.77 (0.1)	0.81 (0.2)	0.54
	Target	0.82 (0.1)	0.93 (0.1)	0.69 (0.0)	0.72 (0.2)	0.70 (0.2)	0.69
Different							
	Prime	0.94 (0.1)	0.88 (0.1)	0.96 (0.1)	0.77 (0.3)	0.79 (0.3)	0.92
	Target	0.58 (0.1)	0.59 (0.1)	0.63 (0.1)	0.60 (0.3)	0.63 (0.1)	0.42
Filler							
	Prime	0.91 (0.1)	0.93 (0.0)	0.78 (0.3)	0.81 (0.2)	0.86 (0.1)	0.80
	Target	0.89 (0.1)	0.85 (0.1)	0.83 (0.2)	0.80 (0.1)	0.88 (0.1)	0.68
Reaction Time							
Same							
	Prime	3013.2 (405.6)	2945.2 (941.7)	3185.3 (671.4)	5071.1 (2203.6)	3936.1 (766.1)	5608.6
	Target	2877.5 (451.9)	3446.7 (444.7)	3200.1 (1030.3)	3799.8 (1751.0)	4813.4 (2190.9)	5142.6
Nonsense							
	Prime	3064.3 (474.5)	3179.2 (22.7)	3171.8 (332.1)	4767.5 (1736.0)	2763.9 (429.6)	12081.2
	Target	2603.5 (238.2)	3059.9 (49.2)	2698.9 (305.4)	3748.7 (1812.7)	3279.2 (112.7)	5250.4
Different							
	Prime	3549.3 (1917.1)	3773.8 (1782.1)	4142.4 (1557.1)	3561.8 (1205.0)	3870.8 (897.5)	3830.0
	Target	3147.9 (487.6)	3332.2 (373.6)	3334.5 (909.5)	4917.8 (3368.2)	4073.8 (1430.3)	4636.3
Filler							
	Prime	3084.7 (431.4)	3390.4 (486.6)	3452.6 (120.6)	4473.6 (2004.9)	3852.2 (563.6)	6638.6
	Target	2945.2 (437.6)	3235.9 (481.5)	3197.3 (516.8)	3777.7 (1573.8)	3527.9 (130.3)	6771.3

RESULTS-Part II

Garden Path Task

Description of Conditions

In brief recap of Garden Path Task methodology, conditions varied along two dimensions. **Plausible-implausible** conditions addressed the influence of **semantic** factors on garden path revision—in particular, sensitivity to semantic cues signaling an incorrect interpretation or “comprehension error”. **Reflexive Absolute Transitive (RAT)** versus **Optional Transitive (OT) verb** conditions examined the influence of **syntactic** factors on garden path revision—i.e., whether syntactic complexity and requirements for syntactic “editing” affect success at revising misinterpretations. Experimental manipulations also varied according to the incorrect interpretation’s “strength” or “resistance to revision.” Thus, semantically plausible and OT verb sentences are more difficult to revise than implausible or RAT verb sentences.

Table 23. Example Sentences and Condition Error Rates Across Groups for the Visual and Auditory Garden Path Task.

		Condition	Item Example	Accuracy Visual/Audit.	
Garden Path	OT	Plausible	As Joe walked the dog napped. Q: Did Joe walk the dog?	0.61 (0.27)	0.44 (0.29)
		Implausible	As the ape ate the tree grew. Q: Did the ape eat the tree?	0.82 (0.24)	0.75 (0.27)
	RAT	Plausible	As Betty woke up Daddy was sleeping in the den. Q: Did Betty wake up Daddy?	0.82 (0.26)	0.64 (0.31)
		Implausible	As the man shaved the cat sat in the tree. Q: Did the man shave the cat?	0.86 (0.24)	0.70 (0.30)
Non-Garden Path	OT	Plausible	The water cooked as Deb drank. Q: Did Deb drink the water?	0.73 (0.27)	0.69 (0.30)
		Implausible	The worm swam in the lake as Jack ate. Q: Did Jack eat the worm?	0.93 (0.19)	0.94 (0.09)
	RAT	Plausible	The baby was in bed as the boy washed. Q: Did the boy wash the baby?	0.93 (0.21)	0.93 (0.18)
		Implausible	The kids swam in the pool as Frank dried off. Q: Did Frank dry off the kids?	0.93 (0.19)	0.82 (0.25)

OT: Optional Transitive, RAT: Reflexive Absolute Transitive

Comparison of the Auditory and Visual Task

In the case of this task, visual and auditory task data were analyzed *together* for several reasons: 1) Overall error patterns were the same in both; 2) Correlations (below) revealed similar patterns for both task versions; and 3) Performance on control sentences was similar in the two versions [$F(1, 95)=1.30$, n.s.; Auditory mean:0.85 ± 0.14; Visual mean: 0.89 ± 0.13].[38]

Task Validation

Appendix A presents extensive background on task characteristics and validity, including an item analysis, inter-condition correlations for accuracy, age-effects (across groups), and confirmation of basic task effects (i.e., garden path effects across groups). Refer to the Appendix A (p. 171) for more detailed information regarding these findings.

Overall, those data supported the effectiveness of the experimental manipulations in each condition and the adequacy of the individual items. Mean accuracy across subjects for each condition is shown in Table 23. Task effects worked as expected, with higher error rates in Garden Path than Non-Garden Path, Plausible than Implausible, and OT than RAT cells. Age was weakly correlated with accuracy in several cells (OT-Plausible, OT-Implausible, RAT-Plausible; r's=.18). As might be expected, IQ was also correlated with accuracy in most conditions but particularly so in experimental conditions (r's ranging from .29 to .48). Age and IQ were therefore controlled in regression and ANOVA analyses. Note that confinement of age and IQ correlations to the experimental (high interference) conditions could suggest the operation of well-developed,

[38] One potential complication, however, were the higher error rates on filler sentences in the auditory task [$F(1,95)=6.05$, $\underline{p}<.02$]. Results were therefore also checked using only visual task data. In all cases, the pattern of results did not change when checked in the visual task only.

automatized, processes underlying control condition performance, whereas the experimental conditions could reflect processes that are still maturing.

Preliminary Analysis of Task Effects in Control Children

A 2 (Garden Path vs. Non-Garden Path) x 2 (Verb Type: RAT vs. Optional Transitive) x 2 (Plausibility: Plausible vs. Implausible) repeated measures analysis of variance was used to determine the effectiveness of experimental manipulations in Control children. Briefly, this analysis revealed the expected garden path (interference[39]) effects and showed utilization of both syntax and semantics to help in revision of garden path misinterpretations, leading to better performance in RAT verb conditions as well as semantically implausible conditions relative to their counterparts (see Figure 3 below).

Thus, this analysis revealed a marginally significant 3-way Garden Path*Verb Type* Plausibility interaction [$F(1,26)=3.43$, $p<.08$, $\eta^2=.12$]. The Garden Path * Plausibility interaction was significant for OT verb sentences [$F(1,26)=10.21$, $p<.01$] but not for RAT verb sentences [$F(1,26)=1.40$, p=ns]. The pooled two-way Garden Path * Plausibility interaction was also significant [$F(1,26)=9.71$, $p<.01$, $\eta=.27$], whereas the Verb Type *Garden Path interaction was not [$F(1,26)=1.77$, $\eta^2=.06$].[40] Finally, there were main effects of Verb-type [$F(1, 26)=32.32$, $p<.001$, $\eta=.55$], Plausibility [$F(1,26)=16.78$, $p<.001$, $\eta^2=.39$], and Garden Path [$F(1,26)=14.81$, $p=.001$, $\eta^2=.36$], and significant 2-way interactions of Verb*Plausibility [$F(1,26)=35.32$, $p<.001$, $\eta^2=.58$; Figure 10 in Appendix A]. All of these effects essentially indicated that the children

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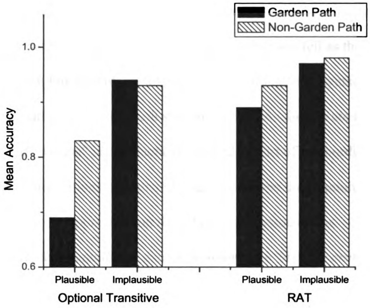
[39] Note that the term "interference" again refers-- not necessarily to *competition* between equivalently-active meanings (i.e., equal competitors)-- but to the ability to handle or suppress inappropriate activation.

[40] Accuracy differences were significant in OT sentences and, in RAT sentences, was marginally worse than accuracy in non-garden path RAT control sentences [$F(1,26)=2.94$, $p<.10$].

were responding to the task as expected and that the manipulations appeared to be challenging interference control mechanisms as intended.

Figure 3. Garden Path by Plausibility Interaction for RAT and OT Verb Conditions in Control Children.



Data Reduction and Review of Planned Comparisons

For ANOVA, relevant interactions were examined; for regressions, composite accuracy scores were created to reduce the total number of these analyses (and familywise Type I error). Table 32 (pg. 174) shows means of derived indexes by group.[41] Three types of effects were of interest here, leading to creation of three main composite scores and/or interaction effects in those respective analyses, as follows.

1) **"Garden Path Effects" (Non-Garden Path minus Garden Path** accuracy score or Garden Path x Non-Garden Path interactions). Here, Garden Path (subordinate-

[41] Correlations among these various derived indexes are shown in Table 40 in Appendix A.

matrix syntactic structure—see example in Table 23,) versus Non-Garden Path (matrix-subordinate syntactic structure—see example in Table 23) comparisons explored ability to "inhibit" or "revise" incorrect syntactic representations *over and above* that of incorrect "pragmatic inferences" (i.e., those drawn from lexical-semantic activation or associations; See example in next paragraph). Put another way, these analyses compared inferential errors resulting from *stimulus*-driven semantic associations in non-garden path sentences (e.g., between "ate" and "banana" in "The banana fell as the ape ate" where ate and banana are not linked syntactically) to those resulting from syntactic (as well as semantic) associations in garden path sentences (e.g.,"As the ape ate the banana fell" where "ate" and "banana" are syntactically linked as part of a subordinate-matrix clause). Experimental manipulations of plausibility and verb-type then examine the success of top-down revision or suppression on these bottom-up associations.

Compare, for example, the garden path sentence *"As Deb drank the water cooked."* to the non-garden path sentence *"The water cooked as Deb drank."* <u>Larger error differences</u> between such sentences (the "Garden Path Effect") indicates less ability to overcome (i.e., *inhibit)* syntactically-established causal relationships (e.g., to causally "disconnect" *water* from *drank*) <u>*relative*</u> to nonspecific semantic associational relationships (i.e., semantic associations between *water* and *drank*). <u>**Prediction**</u>: Deficits in strategic inhibition mechanisms should be associated with larger "garden path effects" of this sort.

2) **"Plausibility Effect"** <u>(**Implausible** accuracy-**Plausible** accuracy and Implausible x Plausible interactions)</u>. Plausibility comparisons provided an index of sensitivity to semantic cues signaling a misinterpretation and ability to deploy

semantically-driven inhibition mechanisms to suppress or revise them (relevant indices: Non-Garden Path Plausibility Effect: OT/RAT, Garden Path Plausibility Effect: OT/RAT). Plausibility comparisons therefore address hypotheses regarding ability to draw upon semantically-driven (yet still strategic or effortful) inhibition mechanisms. Larger differences indicate greater success at utilizing strategic inhibition. **Prediction:** Functioning of top-down, controlled, inhibitory processes should produce re-interpretation of implausible "misinterpretations" (and, consequently, larger differences between Implausible and Plausible accuracies). Thus, opposite to "garden path effects" larger scores indicate better inhibition.

3) **Verb effects** (**RAT** accuracy-**OT** accuracy; RAT x OT interactions): Comparisons of RAT and OT verb manipulations provided an index of sensitivity to syntactic complexity and ability to revise misinterpretations when requirements for effortful processing are reduced-- in effect when the *revision threshold is lowered* (perhaps due to competition from the implicit reflexive object [himself/herself] that weakens the strength of the garden pathed syntactic subordinate verb-noun phrase association). Larger differences between RAT and OT verb accuracies reflect improved performance when inhibition requirements are reduced—i.e., successful inhibition. **Prediction:** Improved accuracy for RAT verbs compared to OT verbs would indicate successful inhibition. Individuals with strategic inhibition impairments may therefore show reduced improvement to RAT verb sentences (i.e., show larger verb effects).

Summary

In brief recap of diagnosis-specific hypotheses, poorer reading/language ability and higher inattention were both predicted to relate to failure to revise garden path misinterpretations (i.e., inhibitory deficits or failure to inhibit inappropriate meanings once activated), specifically when effortful or strategic control was required. Likewise, both ADHD and RD children were predicted to show inhibitory deficits (i.e., higher revision failures) on this task in comparison to Control children. Thus, impaired strategic or effortful inhibitory control should lead to one or more of the following: (a) large garden path scores, (b) small plausibility scores, (c) and small verb effect scores.

Plan of Data Analysis

Analyses will be presented as follows: 1) Dimensional analyses (both correlational and regression) address hypotheses concerning the relationship of reading and attention problems to inhibition and interference effects. Regression analyses examined whether indices of achievement versus inattention uniquely or additively predicted inhibitory ability when controlling for effects of other variables such as estimated IQ and age. 2) Group/categorical analyses (ANOVA's) addressed hypotheses regarding whether ADHD and RD have overlapping cognitive inhibition deficits. These analyses were conducted with condition means rather than derived indexes. Note that to streamline and focus results on the hypotheses, many non-significant findings that were peripheral to primary hypotheses have been placed in Appendix A. The reader will be referred to the Appendix for further information when appropriate.

Note about Reaction Time

Following the procedures of Christianson et al., (2001), reaction time (RT) data were considered supplementary to key questions and were not examined in the current study, because sentence and question length were not controlled within or across conditions. Ideally, eye movement data would be utilized to examine RT effects on garden pathing. Thus, all data described here are accuracy (or error) data.

I now move to specific hypothesis tests. Note that tables of correlation analyses display correlations for numerous indices of a given construct (e.g., reading or inattention). These multiple indices of the same construct are displayed merely to show that findings are robust across multiple measurements. Interpretation of task effects is based upon patterns of results across these indices only. The most important inattention/hyperactivity score is the "Total Inattention" and "Total Hyperactivity" scores, which sum mother and teacher symptoms.

Dimensional Analyses of Inhibitory Effects on Garden Path, Plausibility, and Verb-Effect Difference Scores in Relation to Reading Ability and Attention Problem Scores

IQ, Achievement and Language

Global Inhibition Effects (across verb type and plausibility; Table 24). Dimensional analyses first explored the existence of inhibitory effects across verb type and plausibility to differentiate whether dimensional measures of reading/language could globally predict a failure to "inhibit" or "adjust" incorrect syntactic representations versus whether effects result solely from incorrect "pragmatic inferences" (i.e., inferences drawn from bottom-up lexical-semantic associations). Poorer reading achievement (average of word recognition, spelling, and pseudoword decoding) predicted a larger inhibition deficit (the total garden-path effect across verb type and plausibility). Although age and IQ also strongly negatively predicted the garden-path effect, reading achievement

Table 24. Derived Index Scores for Garden Path and Plausibility Effects for Visual and Auditory versions of the Task:

	Garden Path Effect (NonGardenPath-Garden Path)				Plausibility Effect (Implausible-Plausible)			
	Plausible		Implausible		Garden Path		Non-Garden Path	
	OT	RAT	OT	RAT	OT	RAT	OT	RAT
Visual	0.13 (0.25)	0.12 (0.28)	0.08 (0.18)	0.07 (0.23)	0.23 (0.19)	0.05 (0.21)	0.18 (0.23)	-0.00 (0.23)
Auditory	0.25 (0.22)	0.29 (0.29)	0.19 (0.24)	0.13 (0.34)	0.31 (0.25)	0.05 (0.26)	0.26 (0.27)	-0.11 (0.29)
Total Sample	0.15 (0.25)	0.14 (0.28)	0.09 (0.19)	0.07 (0.25)	0.25 (0.20)	0.05 (0.22)	0.19 (0.24)	-0.02 (0.24)

continued to be a significant predictor in the model after these variables were controlled [$R^2\Delta$=.05, β=-.25, p<.05].

An even stronger predictor of global garden path inhibitory deficits, however, was performance on the measure of expressive language/working memory (Recalling Sentences). Performance on this measure still negatively predicted the global garden path effect after age, IQ, and reading achievement were controlled [$R^2\Delta$=.06, β=-.32, p<.01]. Perhaps not surprisingly, reading no longer significantly predicted the garden path effect when language was also entered as a predictor.

Semantic and Syntactic Influences on Garden Path Effects. To differentiate whether semantic or syntactic experimental manipulations produced unique influences on inhibition, analyses next examined garden path effects (Non-Garden Path – Garden Path accuracy) separately by plausibility and verb-type and these are depicted in Table 25.

These correlations revealed strong, significant, negative associations between measures of reading and language and garden path effects for OT/implausible (but not OT/plausible) sentences. Thus, poorer reading and language abilities were associated with less effectiveness at utilizing semantic information to drive top-down, strategic inhibition of garden path misinterpretations (i.e., larger garden path effects), especially under conditions of higher processing demands (i.e., when the causal structure is more resistant to revision in OT verbs).[42]

Globally poorer language ability was also associated with failure to benefit from reduced inhibition demands from RAT verb sentences (lower revision threshold) regardless of semantic plausibility. This effect was robust to age and IQ control (Table

[42] Note that all children had difficulty revising semantically *plausible* garden path misinterpretations.

25). Thus, poorer language abilities were associated with either 1) difficulty utilizing syntactic rules/structures to recover from garden path errors (e.g., due to a lack of implicit knowledge or proficiency with RAT verbs), or 2) a more severe inhibition deficit that prevents inhibition of misinterpretations even when the causal structure is less resistant to revision. Given that semantic plausibility played *no* role in ameliorating this effect (i.e., it was present for RAT verbs in both the plausible and implausible condition), it seems more likely that language-specific impairments in processing complex syntax rather than an inhibitory deficit produced this finding.

Taken together, findings suggest that language and reading problems are associated with both a) decreased effectiveness at utilizing semantic information to inhibit garden path misinterpretations and b) failure to benefit from reduced inhibition requirements of RAT verbs (stemming either from lack of knowledge about the syntactic features of RAT verbs or from a more severe inhibition deficit). Findings were robust to age and IQ covariance.

Table 25. Garden Path Effects Correlations for IQ, Achievement, and Language.

	Garden Path Effect: Plausible		**Garden Path Effect: Implausible**	
	Optional Transitive	**RAT**	**Optional Transitive**	**RAT**
Age	-.064	-.116	-.071	-.115
Full Scale IQ (Estimated)	-.123	**-.225***	**-.293****	-.081
Mean Reading Score	-.130	-.093	**-.350*****	-.124
Passage Comprehension (SS)	-.138	-.048	**-.310****	-.137
Concepts and Directions (ss)	.090	-.001	**-.349****	**-.204***
Recalling Sentences (ss)	.007	**-.330*****	**-.339*****	**-.262****
LBQ Total Score	.034	.035	**.323****	.010

*** p≤.001, ** p<.01, *p<.05 (2-tailed), + p<.10 (2-tailed)

Table 26. Effect of Verb Type on Garden Path Effects in Plausible Conditions.

	Variable	R^2	Adj. R^2	ΔR^2	F for $R^2\Delta$	β†	T
1	**Recalling Sentences**	**.07**	**.06**	**.07**	**7.07 (1,95)****	**.26**	**2.66****
2							
Step 1	Age	.00	-.01	.00	0.22 (1,95)	.11	1.08
Step 2	IQ	.01	-.01	.01	0.99 (1,94)	-.08	-0.64
Step 3	**Recalling Sentences**	**.09**	**.06**	**.07**	**7.39 (1,93)****	**.33**	**2.72****
3							
Step 1	Age, IQ	.01	-.01	.01	0.61 (2,94)	.08	-0.31
						-.04	0.77
Step 2	Reading Average	.02	-.02	.00	0.22 (1,93)	-.16	-1.34
Step 3	**Recalling Sentences**	**.10**	**.06**	**.09**	**9.03 (1,92)****	**.38**	**3.01****

Comparison of Garden Path versus Non-Garden Path Effects (Inhibition versus Activation Effects). As a final step, correlational analyses also examined plausibility effects (Implausible – Plausible accuracy) separately for garden path and non-garden path sentences to determine whether effects were related *solely* to performance in one condition or the other.

This analysis found the strongest effects on non-garden path sentences. Thus, lower reading achievement, language abilities, and IQ, were globally associated with higher sensitivity to semantic plausibility in *non-garden path sentences*. In other words, those with poorer abilities in these areas continued to rely upon pragmatic inferential aspects of the sentence, answering based upon bottom-up lexical-semantic associations, even in non-syntactically complex sentences. No such finding occurred in the RAT/Non-Garden Path condition (where the RAT verb all but prevents misinterpretation of verb-object relationships).

Language and reading comprehension abilities were also associated with performance on garden path sentences. Interestingly, findings suggested that lower reading, language, and IQ were also associated with increased reliance on bottom-up lexical-semantic associations or even a possible *stronger* reliance on semantic implausibility (i.e., increased utilization of top-down, semantically-driven suppression—for revision of syntactically complex OT garden path interpretations). This finding suggested that language and reading problems may be associated with global difficulties processing complex syntax and a subsequent reliance on inferences from bottom-up lexical-semantic activation (i.e., verb-noun phrase associations).

Table 27. Correlations between Plausibility Effects and Indices of Achievement and Language.

	Plausibility Effect: Garden Path		**Plausibility Effect: Non-Garden Path**	
	Optional Transitive	**RAT**	**Optional Transitive**	**RAT**
Age	-.060	-.051	-.043	-.029
Full Scale IQ (Estimated)	**-.274****	-.140	**-.348*****	.052
Mean Reading Score	-.110	.084	**-.245***	.057
WJ Word Attack (SS)	-.064	.061	**-.262****	.030
Passage Comprehension (SS)	**-.178+**	.116	**-.263****	.020
Concepts and Directions (ss)	-.006	.114	**-.384*****	-.104
Recalling Sentences (ss)	**-.190+**	-.028	**-.448*****	.090

*** $p \leq .001$, ** $p < .01$, *$p < .05$ (2-tailed), + $p < .10$ (2-tailed); Plausibility Effect=Implausible-Plausible

Summary. Taken together, dimensional analyses suggested that language and reading problems are associated with both a) global difficulties processing complex syntax with a subsequent reliance on inferences from bottom-up lexical-semantic activation (i.e., verb-noun phrase agreement), and b) decreased effectiveness at utilizing semantic information to inhibit garden path misinterpretations (perhaps as a byproduct of problems with complex syntax).

Inattention, Hyperactivity, and Learning

Global Garden Path Effects (across verb type and plausibility; Table 28). Dimensional analyses first explored the existence of inhibitory effects across verb type and plausibility to differentiate whether dimensional measures of inattention/ hyperactivity globally predict a failure to "inhibit" or "adjust" incorrect syntactic representations versus whether effects are driven by "pragmatic inferences." (i.e., inferences based upon bottom-up lexical-semantic associations). As shown in Table 28, hyperactivity significantly predicted the global garden path effect, but this effect was not robust to age and IQ control.

Semantic and Syntactic Influences on Garden Path Effects. To differentiate whether semantic or syntactic experimental manipulations might have obscured garden path inhibition effects, analyses next examined garden path effects (Non-Garden Path – Garden Path accuracy) separately by plausibility and verb-type. These are depicted in Table 28. Inattention and hyperactivity were not associated with garden path effects in either the OT or RAT *plausible* condition, suggesting that all children experienced difficulty revising misinterpretations in these conditions.

Inattention and hyperactivity were, however, associated with larger garden path effects in the OT/implausible condition, such that more inattention and hyperactivity was associated with less effectiveness at utilizing semantic information (i.e., implausibility) to drive top-down, strategic inhibition of garden path misinterpretations (i.e., larger garden path effects), especially under conditions requiring more inhibition for success (i.e., OT verb's greater resistance to revision). Likewise, hyperactivity ratings (but *not* inattention ratings) were also associated with larger garden path effects (strategic inhibition problems) in the RAT/implausible condition, which might reflect consequences of more severe inhibitory deficits.[43]

Table 28. Garden Path Effects: Correlations with Inattention and Hyperactivity.

	Garden Path Effect: Plausible		Garden Path Effect: Implausible	
	Optional Transitive	**RAT**	**Optional Transitive**	**RAT**
Total Inattentive Symptoms‡	-.098	.112	**.244***	.083
Total Hyperactivity Symptoms‡	.018	.060	**.266****	**.222***
Mother-Ratings				
ARS Total Raw-Mother	-.059	.056	**.254***	.143
ARS Inattentive Raw	-.085	.072	**.247***	.114
ARS Hyperactivity Raw	-.023	.030	**.230***	.150
Teacher-Ratings				
ARS Total Raw	.016	.102	**.311****	**.226***
ARS Inattentive Raw	.009	.090	**.299****	**.174+**
ARS Hyperactivity Raw	.021	.099	**.281****	**.249***
Conners ADHD Index T	-.055	.019	**.354*****	.158
BASC Learning	.051	.093	**.392*****	**.177+**

***p<.001, **p<.01, * p<.05, + p<.10 (2-tailed)

‡ Mother+Teacher symptoms by the "OR algorithm"

Comparison of Inhibition (garden path) versus Semantic Activation (pragmatic inference) Effects in Relation to Semantic Plausibility and Verb Type. As a final step, correlational analyses also examined plausibility effects (Implausible – Plausible accuracy) separately for garden path and non-garden path sentences to determine whether effects were related *solely* to performance in one condition or the other. Correlations between measures of inattention/hyperactivity and plausibility effects are shown in Table 29 below.

[43] Findings of no association between inattention and hyperactivity and garden path effects in the *plausible* conditions reflects the fact that *all* subjects experienced un-revised garden path misinterpretations (for clarification, refer to means for Control children in Table 31,).

These analyses revealed a differential effect of hyperactivity and inattention. Higher levels of hyperactivity were marginally associated with *smaller* plausibility effects (thus, worse interference control) in the garden path/OT condition, indicating failure to utilize semantics to overcome garden path misinterpretations under highly "revision-resistant" conditions (i.e., OT verb sentences).[44,45]

Table 29. Correlation between Plausibility Effects and Inattention and Hyperactivity.

	Garden Path Plausibility Effect		**Non-Garden Path Plausibility Effect**	
	Optional Transitive	**RAT**	**Optional Transitive**	**RAT**
Total Inattentive Symptoms‡	-.157	-.016	.165	-.059
Total Hyperactivity Symptoms‡	**-.186+**	-.075	.038	.089
<u>Mother-Ratings</u>				
ARS Total Raw-Mother	-.073	-.087	**.206***	.003
ARS Inattentive Raw	-.039	-.047	**.256***	-.010
ARS Hyperactivity Raw	-.100	-.121	.125	.017
BASC Attention	-.001	.014	**.282****	-.049
<u>Teacher-Ratings</u>				
ARS Total Raw	**-.179+**	-.065	.082	.055
ARS Inattentive Raw	-.116	-.077	.134	.004
ARS Hyperactivity Raw	**-.220***	-.043	.017	.100
BASC Attention	-.070	-.083	**.277****	-.128
BASC Learning	.009	-.115	**.275****	-.031

**p<.01; * p<.05; + p<.08 (2-tailed)
‡ Mother+Teacher symptoms by the "OR algorithm"

Symptoms of inattention, on the other hand, were correlated with plausibility effects in the *non-garden path/OT* condition, such that <u>higher levels of inattention</u> were related to <u>more reliance on semantic inferential reasoning</u> (i.e., bottom-up, lexical-semantic associations) in less syntactically complex conditions (i.e., control, non-garden

[44] This finding is *opposite* to findings for language/reading.
[45] Note that this is a weaker test of the hypothesis, since it does not take into account over-reliance on bottom-up semantic mechanisms controlled by the comparison to Non-Garden Path sentences.

path sentences, for example, "The banana fell as the ape ate."). High levels of inattention were thus associated with a greater tendency to be influenced by "bottom-up" semantic activation of the verb-object relationship, even when such a relationship was not syntactically licensed. Such difficulties might relate to either a) insensitivity to bottom up syntactic inputs or b) failure of automatized suppression mechanisms that should control interference from irrelevant lexical-semantic activation in order to support construction of accurate text-level representations (e.g., as proposed by Gernsbacher's (1997) Structure Building Framework).[46]

Summary. Inattention and hyperactivity were both associated with less effectiveness at utilizing semantic information (i.e., implausibility) in the form of top-down, strategic inhibition of activated misinterpretations. There was some suggestion, however, that for inattention this effect was driven by over-reliance on semantic inferential reasoning (i.e., bottom-up, lexical-semantic associations) reflective of possible failures of a more automatic mechanism that should block irrelevant activation in order to allow more efficient construction of accurate text-level representations. In contrast, hyperactivity may be more associated with failure of effortful and strategic mechanisms.

I now turn to findings for categorical/group differences.

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[46] Note that the key test of this association: "Total Inattentive Symptoms" was not significant. Thus, this result must be interpreted with caution.

Table 30. Total Garden Path Effect (across Plausibility and Verb Types)

	Variable	R^2	Adj. R^2	Δ R^2	F for R^2Δ	β‡	T
1	**Mean Achievement**	**.08**	**.07**	**.08**	**7.68 (1,95)******	**-.27**	**-2.77****
2							
Step 1	**Age**	**.18**	**.15**	**.05**	**5.46 (1,93)***	**-.27**	**-2.76****
Step 2	**Full Scale IQ (estimated)**					**-.23**	**-2.18***
Step 3	**Mean Achievement**					**-.25**	**-2.34***
1	**Total Inattention Symptoms**	.02	.01	.02	1.66 (1,95)	.13	1.29
1							
Step 1	**Age**	.13	.11	.13	7.18 (2,94)†	-.23	-2.12*
	Full Scale IQ					-.27	-2.67**
Step 2	**Mean Achievement**	.18	.15	.05	2.70 (2,92)$^{+}$	-.25	-2.25*
	Total Inattention Symptoms					.01	0.07
Step 3	**Interaction (Achiev.*Inatt.)**	.18	.14	.00	0.00 (1,91)	-.00	-0.04
1	**Total Hyperactive Symptoms**	**.05**	**.04**	**.05**	**4.99 (1,95)***	**.22**	**2.23***
2							
Step 1	**Age (months)**	.16	.13	.02	2.62 (1,93)	-.20	-2.01*
Step 2	**Full Scale IQ (estimated)**					-.30	-3.09**
Step 3	**Total Hyperactive Symptoms**					.16	1.62
1	**Recalling Sentences**	**.15**	**.14**	**.15**	**16.85(1,95)†**	**-.39**	**-4.11†**
2	**Age (months)**	**.23**	**.20**	**.09**	**11.21(1,93)†**	**-.26**	**-2.82****
	Full Scale IQ					**-.13**	**-1.16**
	Recalling Sentences					**-.38**	**-3.35****
3							
Step 1	**Age**	**.24**	**.21**	**.06**	**7.75 (1,92)***	**-.30**	**-3.10****
	Full Scale IQ					**-.09**	**-0.79**
Step 2	**Mean Achievement**					**-.16**	**-1.50**
Step 3	**Recalling Sentences**					**-.32**	**-2.78****
1	**Passage Comprehension**	**.06**	**.05**	**.06**	**6.16 (1,95)***	**-.25**	**-2.48***
2	**Age**	.15	.12	.02	1.68 (1,93)	-.23	-2.32*
	Full Scale IQ					-.25	-2.20*
	Passage Comprehension					-.15	-1.30

$^{\dagger}p<.001$, $^{**}p<.01$, $^{*}p<.05$

Categorical Hypotheses: Analysis of Group Differences on Garden Path (i.e., Inhibition) Effects

In addition to dimensional analyses on the variables of interest, categorical analyses evaluated hypotheses regarding group differences. Such comparisons are important for determining whether patterns of impairment differ *at the level of clinical diagnosis* (i.e., when symptoms reach a certain level of severity) versus whether impairments become evident along a continuum as symptom severity increases (i.e., as seen in dimensional analyses). To evaluate categorical hypotheses, 6 additional repeated measures analyses of variance were performed. These analyses relied upon condition means rather than the earlier index scores, because findings are conceptually easier to understand and to depict graphically. To maximize inclusion of participants, ADHD-C and ADHD-I children were combined into one ADHD group (based upon findings in regression analyses related primarily to inattention but not to hyperactivity). Also, those with ADHD+RD were included in the RD group but not in the ADHD group.

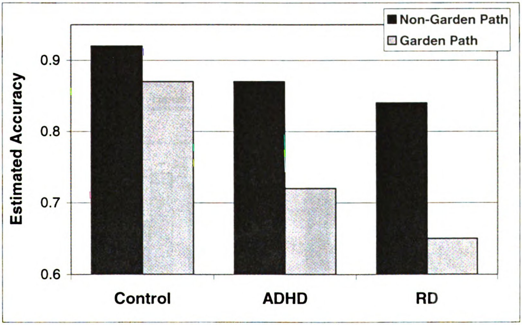
First, to examine performance for all conditions and all groups, a 2 x 2 x 2 x 3 omnibus repeated measures ANOVA was used, with Garden Path Condition (Garden Path versus Non-Garden Path), Plausibility (Plausible vs. Implausible), and Verb Type (RAT vs. Optional Transitive) as within subjects factors and diagnostic group (Control, ADHD, RD) as the between subjects factor. This omnibus analysis revealed a main effect of group [$F(2,79)=6.26$, $p<.01$], a significant 2-way Group x Garden Path condition interaction [$F(2,79)=4.00$, $p<.03$, $\eta^2=.09$; Figure 4], and a significant 3-way Verb x Plausibility x Group interaction [$F(2,78)=4.68$, $p<.02$, $\eta^2=.11$]. There was also a main effect of verb type [$F(1, 79)=44.34$, $p<.001$, $\eta^2=.36$]. The 4-way interaction and the

Verb x Garden Path x Group and Plausibility x Garden Path x Group interactions were non-significant.

Taken together, then, this omnibus analysis revealed global differences in ability to revise garden path misinterpretations among groups and was indicative of ADHD and RD impairments in effortful inhibition and with utilization of top-down, semantically-driven inhibition mechanisms.

As a secondary comparison to determine whether verb or plausibility had any effect on susceptibility to making errors on <u>garden path sentences alone</u> (i.e., not in comparison to non-garden path sentences), an additional 2 x 2 x 3 omnibus repeated measures ANOVA was employed. Plausibility (Plausible vs. Implausible) and Verb (RAT vs. OT) served as the within subjects factors and Group (Control, ADHD, RD) served as the between subjects factor. This analysis revealed no significant interactions with group.

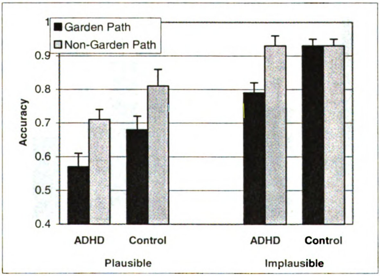
Figure 4. Garden Path x Group Interaction.



To deconstruct omnibus findings, a series of additional planned 2 (Garden Path vs. Non-Garden Path) x 2 (Plausible vs. Implausible) x 2 (Group) post-hoc repeated measures ANOVAs explored: 1) ADHD vs. Controls on a) RAT verb sentences and b) OT verb sentences and 2) RD vs. Controls on a) RAT verb sentences and b) OT verb sentences. Sex, age, and IQ effects were also explored, but these did not substantially alter any findings.

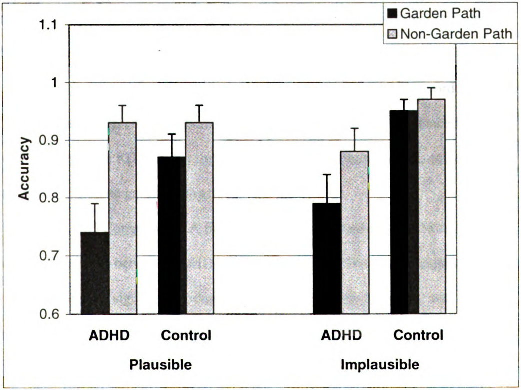
Control versus ADHD. For OT verb sentences, the 2 x 2 x 2 ANOVA revealed a marginally significant 3-way interaction [$F(1, 53)=3.26$, $p<.08$, $\eta^2=.06$], in which ADHD and Control children demonstrated similar differences between garden path and non-garden path sentences in the plausible condition, but ADHD children continued to show a much stronger garden path effect in the implausible condition (Figure 6). Thus, for OT verb sentences, there was modest support for an ADHD-related deficit in effortful inhibition related to an inability to use semantics to aid in revision of garden path misinterpretations.

Figure 5. Comparison of Garden Path Effects for Control vs. ADHD-C children for OT verbs.



For RAT verb sentences, the 2x2x2 ANOVA revealed no significant 3-way Plausibility*Garden Path*Group interaction [F(1,53)=0.02]. However, the Group x Garden Path interaction was significant [F(1,53)=7.17, p=.01, η^2=.12], such that ADHD children continued to show garden path effects (in the plausible and implausible conditions) for RAT verb sentences, whereas Control children did not experience garden pathing for these verbs (Figure 6). RAT verb-type was therefore associated with failure to revise or adjust incorrect garden path interpretations in ADHD children (regardless of the plausibility of the misinterpretation). Thus, as is also evident in Figure 6, ADHD children continued to receive no benefit from semantic implausibility (although the large standard deviations indicate that the group's performance was quite variable).

Figure 6. Comparison of Garden Path Effects for ADHD vs. Control Children on RAT verbs.



Control vs. RD. RD versus Control differences were also examined with the 2 (Garden Path vs. Non-Garden Path) x 2 (Plausible vs. Implausible) x 2 (RD vs. Control) ANOVA's separately for OT and RAT verb types.

For OT verb sentences, the 3-way interaction narrowly missed significance [$F(1,45)=2.40$, $p=.13$, $\eta^2=.05$] but showed a similar pattern to that found in the comparison of ADHD and Control children (see Figure 5). Thus, as with ADHD children, for OT verb sentences, RD was associated with a possible trend towards an effortful inhibitory deficit at the semantic/inferential level of interpretation.

For RAT verb sentences, the 2x2x2 ANOVA revealed no significant 3-way interaction [$F(1,45)=0.00$]. However, the Group x Garden Path interaction was significant [$F(1,45)=3.95$, $p=.05$, $\eta^2=.08$], such that RD children continued to show garden path effects for RAT verb sentences in the plausible as well as implausible condition (whereas Control children exhibited substantially reduced garden path effects in the plausible condition). Thus, similar to ADHD children, RD children continued to have difficulty revising garden path sentences even when the syntactic structure afforded by the RAT verb prevented them from having to make syntactic revisions in order to revise semantic misinterpretations (thematic role assignments). Some evidence from correlational analyses in RD children suggested that they may have trouble utilizing syntactic rules to mitigate garden path effects.

ADHD vs. RD Comparison. A final post-hoc repeated measures ANOVA explored the differences between ADHD and RD (including RD+ADHD) children. This comparison revealed no significant group differences. When the RD group was constrained to exclude comorbid ADHD+RD children results remained unchanged. Note that the informal check on differences between the comorbid ADHD+RD group using two between group factors (ADHD: yes/no, RD: yes/no) revealed no significant between group factor interaction.

Summary of Findings on the Garden Path Task Overall

Taken together, results for this task and the three main types of interference effects examined (garden path effects, plausibility effects, and verb type effects) suggest that children with ADHD and RD both have problems utilizing semantically-driven, effortful inhibition to revise misinterpretations. These inhibition failures may, however, have different sources. Thus, RD impairments may derive from difficulties with complex syntactic analysis and resultant resource limitations. On the other hand, ADHD impairments may derive directly from failures in two kinds of inhibition (or suppression) mechanisms. Which mechanism is involved may differ by which ADHD symptom domain is at issue. Thus, it appeared that behavioral symptoms of inattention-disorganization were associated with failure of automatic suppression mechanisms that control "bottom up" interfering information before it has to be cognitively processed. Hyperactivity was associated with weakness in a more effortful mechanism that should enable suppression of information at the level of cognitive processing. .

Table 31. Condition Means by Diagnostic Groups.

Condition	Control N=23	ADHD-Only		RD-Only N=13	RD+ADHD	
		Combined N=24	Inattentive N=5		ADHD-C N=4	ADHD-I N=3
Accuracy						
OT						
Plausible	0.69 (0.22)	0.58 (0.29)	0.52 (0.23)	0.49 (0.28)	0.45 (0.33)	0.30 (0.17)
Implausible	0.94 (0.09)	0.76 (0.22)	0.86 (0.15)	0.80 (0.17)	0.72 (0.35)	0.53 (0.42)
OT-Control						
Plausible	0.83 (0.26)	0.73 (0.21)	0.56 (0.26)	0.71 (0.33)	0.51 (0.24)	0.53 (0.31)
Implausible	0.93 (0.12)	0.92 (0.21)	0.96 (0.09)	0.92 (0.13)	0.89 (0.13)	0.93 (0.12)
RAT						
Plausible	0.89 (0.24)	0.73 (0.30)	0.75 (0.43)	0.73 (0.26)	0.79 (0.14)	0.58 (0.38)
Implausible	0.97 (0.09)	0.75 (0.31)	0.90 (0.22)	0.73 (0.24)	0.81 (0.24)	0.50 (0.43)
RAT-Control						
Plausible	0.93 (0.18)	0.91 (0.19)	1.00 (0.0)	0.92 (0.28)	0.75 (0.50)	0.83 (0.29)
Implausible	0.98 (0.11)	0.91 (0.19)	0.70 (0.44)	0.81 (0.25)	1.00 (0.0)	0.67 (0.29)
Filler	0.88 (0.12)	0.83 (0.12)	0.84 (0.08)	0.79 (0.14)	0.69 (0.19)	0.76 (0.18)

Table 32. Derived Index Scores for Garden Path and Plausibility Effects by Group:

	Garden Path & Plausibility Interaction Effect		Garden Path Effect (NonGardenPath-Garden Path)				Plausibility Effect (Implausible-Plausible)			
			Plausible		Implausible		Garden Path		Non-Garden Path	
	OT	RAT	OT	RAT	OT	RAT	OT	RAT	OT	RAT
Control	0.14 (0.22)	0.04 (0.17)	0.14 (0.18)	0.06 (0.17)	0.00 (0.11)	0.02 (0.09)	0.25 (0.19)	0.07 (0.21)	0.12 (0.21)	0.03 (0.14)
ADHD-C	0.00 (0.33)	0.03 (0.38)	0.15 (0.29)	0.18 (0.28)	0.15 (0.23)	0.15 (0.31)	0.19 (0.20)	0.02 (0.22)	0.19 (0.20)	-0.01 (0.24)
ADHD-I	-0.02 (0.29)	0.35 (0.46)	0.07 (0.25)	0.22 (0.34)	0.09 (0.15)	-0.13 (0.39)	0.31 (0.10)	0.13 (0.19)	0.34 (0.28)	-0.22 (0.39)
RD	0.09 (0.30)	0.12 (0.49)	0.22 (0.29)	0.19 (0.38)	0.12 (0.19)	0.08 (0.30)	0.31 (0.21)	0.00 (0.32)	0.22 (0.33)	-0.12 (0.30)
RD+ADHD										
ADHD-C	-0.10 (0.25)	-0.23 (0.69)	0.06 (0.13)	-0.04 (0.49)	0.17 (0.22)	0.19 (0.24)	0.27 (0.35)	0.02 (0.21)	0.38 (0.21)	0.25 (0.50)
ADHD-I	-0.17 (0.45)	0.08 (0.38)	0.23 (0.21)	0.25 (0.43)	0.40 (0.35)	0.17 (0.14)	0.23 (0.25)	-0.08 (0.14)	0.40 (0.20)	-0.17 (0.29)

DISCUSSION

Controlling interference from competing thoughts or information in one's mind is crucial for accurately interpreting and functioning in the world. Children operate under constant requirements for such suppression—for example, suppressing the thought of the ice cream they were told they couldn't have to help them control the behavior of asking their mother for it over and over again, tuning out thoughts of what they will do after school to attend to their teacher's instructions, or ignoring the television playing in the next room to focus on their homework. In addition, the ability to identify and correct one's mistakes (i.e., self-monitoring), revise expectations to adapt to change, and even to "forgive and forget" are crucial components to social-emotional functioning.

The inattention and disorganization that subsume many of these behaviors are key diagnostic markers of ADHD and typical behavioral descriptors of these children. Puzzlingly, however, empirical evidence for associated neurocognitive deficits has been difficult to document within a laboratory setting (contrary to the extensive empirical support for behavioral dysregulation and "output" deficits—e.g., *response disinhibition* on Logan's Stop Task—that are related to behavioral impulsivity, emotional reactivity, and disinhibition).

Cognitive inhibition (i.e., the capacity to resist interference from irrelevant information and suppress activated cognitive contents) is one theoretically promising but understudied candidate for attention and organizational impairments in ADHD. The distinction between automatic (i.e., unconscious and resource-independent) versus strategic (i.e., conscious, effortful, and resource-dependent) inhibition impairments is also a key area for clarification. Of the few studies that have explored cognitive inhibition in

ADHD, most have largely failed to support such impairments (e.g., using directed forgetting paradigms; Harnishfeger, 1995). Few studies had heretofore examined whether inhibitory impairments could be detected in *higher-order* cognition, particularly in the language domain. This lack of research is surprising since language plays a critical role in self-regulation (Barkley, 1997) and social adjustment, ADHD has a high rate of comorbidity with language/reading problems, and the cognitive field has produced a modest body of literature on interference control in language processing.

Dempster (1993) posited that control over interference does not develop uniformly across all domains of processing and, instead, develops from an "outward to inward" direction, with children initially developing the ability to suppress motoric interference, then perceptual interference, and, finally, linguistic interference (proposed to dominate beginning around 6 years of age). Because most ADHD studies focus on elementary school-aged children (ages 6-10), measures of interference in the language domain may be most sensitive to the effects of inhibitory impairments on cognition *during* this developmental stage.

This study sought to utilize the enhanced sensitivity provided by cognitive language comprehension tasks reliant upon putative inhibitory mechanisms[47] (i.e., those that involve resolving competition among competing cognitive contents or protecting working memory from extraneous or irrelevant information) to examine four aims: 1) whether children with ADHD exhibit problems with higher-order language comprehension (even in the absence of a learning disability), 2) if inhibitory deficits in

[47] Ability to suppress or overcome irrelevant information in cognition is the primary measure of interest in this study. Whether this mechanism of suppression is truly inhibitory is a matter that continues to receive widespread debate but is beyond the scope of this study. For current purposes, this process will be referred to as either inhibition or suppression with the understanding that the true underlying nature of this suppression (i.e., whether it is activation or inhibition-related) remains unresolved.

ADHD (well-established in the motor output domain) extend to the area of cognitive processing and, in particular, emerge during language comprehension; 3) whether children with RD also show evidence of inhibitory-related language impairments (beyond generalized language deficits), as is suggested by the cognitive literature, and 4) whether impairments on inhibitory language tasks, if they exist in ADHD and RD, clarify the etiology of the high rate of co-occurrence between the two disorders.

These aims were explored with two cognitive tasks of language comprehension believed to require inhibition and which varied according to their requirements for automatic versus strategic/effortful suppression. The Ambiguous Words Task examined utilization of both automatic and effortful inhibition for interference control in language comprehension. The Garden Path Task, on the other hand, assessed ability to utilize strategic and effortful control to revise misinterpretations.

Briefly, results of the current study supported the existence of language-related inhibition impairments in children with ADHD in both expected and surprising ways. As predicted, higher levels of inattention (or ADHD diagnosis) were associated with poorer utilization of "top-down," effortful, inhibitory control of irrelevant information during language comprehension. Somewhat less expected, *girls* but not *boys with ADHD* exhibited additional difficulties with relatively automatic inhibition of irrelevant information during language processing.

Although analyses for RD children were necessarily preliminary and exploratory, findings suggested that primary problems with lower-order language produced patterns of impairments on inhibitory-related language processing much the same as those found in ADHD children. Compared to Controls, children with RD exhibited weaknesses in both automatic and effortful inhibition that were dimensionally related to reading ability (but not attention) within that group. Preliminary findings therefore suggested that lower-order language deficits might affect higher-order inhibition of irrelevant information in language comprehension in those children.

Discussion now moves to elaboration of experimental findings, their implications for understanding ADHD and RD, and future studies. Findings for interference control on the Ambiguous Words Task will be addressed first and will then be followed by findings for revision of misinterpretations on the Garden Path Task.

Interference Control

Relationship of Inattention to Interference Control

Current findings revealed that children with ADHD do indeed have difficulty resolving interference from competing verbal information during higher-order cognition. Functionally, this difficulty affects reading and listening comprehension—specifically, the ability to draw conclusions or make connections about material within text (or discourse).

Thus, on the Ambiguous Words Task, findings for sentence-level lexical ambiguity resolution in the sample of ADHD and Control children revealed an association between higher inattention (or ADHD diagnosis, but *not hyperactivity*) and weaker interference control[48]—manifested by both *more* errors (i.e., higher Costs) and relatively *slower* response speed[49]. Such impairments are consistent with deficits in "cognitive inhibition," in that previously activated cognitive contents remain in working

[48] Following different-meaning *as well as* no-meaning/nonsense primes (in contrast to Control children who showed modest facilitation—i.e., decreased error rates). Performance in the nonsense condition therefore actually *also* may be a byproduct of inhibitory deficits.
[49] Recall that RT for all subjects was facilitated for targets (compared to primes) but ADHD children experienced less facilitation.

memory and then interfere with subsequent processing (Harnishfeger, 1995). If results are, in fact, a byproduct of poor cognitive suppression, then the pattern of accuracy and RT costs can perhaps be understood in the following way. Consistent with exhaustive access models of lexical ambiguity resolution, *all* groups (regardless of clinical diagnosis) experienced continued activation of *both* homonym meanings after prime processing (demonstrated by relative facilitation in mean RT to alternate-meaning targets). Sustained activation of both homonym meanings produces competition during target presentation. The success with which the now context-inappropriate dominant meaning is suppressed during subordinate-meaning target access then influences the resolution of this competition and is dependent on the efficiency of interference control mechanisms (Neill, Valdes, & Terry, 1995). In the context of weaker suppression abilities, the result would be slower ambiguity resolution and more errors.[50]

Using a "horse race" analogy, relatively equivalent levels of activation for both the prime (dominant) and target (subordinate) meanings of the homonym should lead to increased chances of incorrectly selecting the dominant meaning for the target sentence (i.e., the horse race ends prematurely with the incorrect dominant meaning reaching the activation threshold for selection first or with the correct subordinate meaning never achieving a high enough activation for selection) *or* to taking more time to access the target meaning (i.e., a longer time for the subordinate meaning to achieve selection thresholds; recall that RT data were used *only* when both prime and target responses were correct.).

[50] Note that by this logic, the very mild costs obtained by ADHD children to targets following no-meaning primes could be consistent with similar mechanisms at work in over-coming the slight advantage likely received by the dominant homograph meaning (due to its greater frequency) in the absence of specific context priming. Control children did not experience such costs in accuracy.

While deficits in interference control have never been studied in relationship to language functioning in ADHD, such impairments are not without precedence in other domains. Casey (2001), for example, found children with ADHD to exhibit deficits on a stimulus selection task requiring suppression of previously attended *stimulus attributes* and proposed that these deficits may be associated with impairments in dorsolateral prefrontal cortex.

ADHD-related interference control problems in the domain of language comprehension have widespread implications for the language functioning of these children. Dempster (1993), for example, described a number of text characteristics that can produce interference during reading, including unrelated statements about the same topic, involvement of the same set of characters in different activities, ambiguous messages with more than one meaning, and irrelevant or contradictory text information. Thus, interference control problems would have a pervasive impact on the reading comprehension abilities of children with ADHD and may explain prior empirical findings as well as anecdotal clinical evidence of reading comprehension difficulties and sub-par achievement in this population (Brock & Knapp, 1996; Lorch et al., 1999; Forness, Youpa, Hanna, Cantwell, & Swanson, 1992). Problems with language-related interference control could also explain problems with organization, effectiveness of internalized language in guiding or regulating behavior, and perhaps even to problems with emotion regulation.

One primary means by which interference control problems may affect language comprehension is through a reduced ability to make inferences. McInnes and colleagues (2003) found children with ADHD to have impairments in the inferential aspects of auditory passage comprehension (i.e., the ability to make connections among text ideas and to "read-between-the-lines") despite intact retention of concrete facts. Thus, current findings extend those of McInnes and colleagues by suggesting that similar inference difficulties (i.e., determining whether a sentence makes sense) can occur under relatively non-demanding language processing conditions (i.e., sentence-level rather than passage-level comprehension) and under relatively minimal demands for "off-line" retrieval of information from memory. In particular, as posited by Gernsbacher's (1997) Structure Building Framework, failure to suppress irrelevant information when constructing sentence-level representations (in this case the context-inappropriate meaning of a homonym) may impair construction of accurate causal chains and lead to impaired reading comprehension and inference failures (e.g., ADHD-related problems with retaining irrelevant story details at the expense of more important ones [Lorch et al., 1999]).

Other prior studies on language or reading comprehension in ADHD also find impairments under conditions most likely to involve interference control. Lorch and colleagues (1999) found that ADHD children had impaired recall of television stories only under divided attention processing conditions and retained irrelevant story details at the expense of more important ones. These authors hypothesized that failure to suppress irrelevant details interfered with selection of important story units. Current findings are consistent with this interpretation.

A final means through which cognitive inhibition and interference control impairments would influence language functioning in ADHD children is through their impact on internalized speech, which is thought to be critical for behavioral control (Berk

& Potts, 1991) and which is deficient in ADHD (Copeland, 1979). Internalized language is thought to influence executive functioning and the development of cognitive maps/schematas of the world that produce complex thought and abstract thinking (Damico, Damico, and Armstrong, 1999; Barkley, 1997). Problems in interference control could, for instance, affect this "internal language system" in much the same way as it does language comprehension. Competition and interference from competing thoughts could produce difficulties in the maintenance of coherent representations of internal goals or in construction of a causal chain of steps to achieve these goals. Interference might also produce difficulties in the use of language to reason through problems (i.e., constructing a coherent, causally-structured, inner dialogue) and in the verbal mediation of problem-solving or behavior. Thus, problems with interference control in internalized language—if replicated—could have significant implications for understanding executive functioning impairments in ADHD.

The current study raised the additional possibility of ADHD-related gender differences in interference control impairments. A number of recent studies have demonstrated that ADHD girls have the same executive functioning deficits as boys (Nigg, Blaskey, Huang-Pollock, & Rappley, 2002; Houghton et. al., 1999), but few studies have *directly* compared boys and girls. In this study, girls with ADHD experienced the most severe interference, demonstrating *twice* the error rate (costs) for alternate-meaning targets as non-ADHD children (boys and girls) and ADHD boys.[51] These robust interference effects in ADHD girls are particularly intriguing, since they suggest the possibility of an etiological mechanism unique to girls with the disorder.

[51] Boys did, however, show evidence of problems with interference control in the no-meaning priming condition and in RT data.

One possibility is that girls with ADHD have more severe inhibition impairments than boys with ADHD. Nigg and colleagues (2002), for instance, found that ADHD-I girls but not boys had response inhibition deficits, suggesting the possibility of more severe deficits in diagnosed girls. Other evidence for wider-spread or more severe cognitive impairments in girls with ADHD is findings of increased vulnerability to co-occurring language/reading disorders--especially in those with ADHD-I (Berry, Shaywitz, & Shaywitz, 1985; Love & Thompson, 1988; Tirsoh & Cohen, 1998). Alternatively, ADHD girls with certain cognitive deficits could represent a biologically distinct subgroup of ADHD children (Doyle, Faraone, DuPre, & Biederman, 2001).

Findings of more global or more severe inhibition deficits in girls with ADHD would suggest the possibility of ascertainment biases (i.e., only severely impaired girls are referred for treatment due to demonstration of fewer behavior problems) or polygenetic transmission factors (i.e., girls must carry a higher genetic load and meet a higher threshold before phenotypic impairment becomes evident; Berry, Shaywitz, & Shaywitz, 1985) that influence the expression of the disorder in girls. Given the very small group of girls in the current study, these findings will need to be replicated.

Overall, then, ADHD and inattention were associated with language-related problems in interference control.[52] Still unanswered, however, is the secondary question of whether reading abilities have a similar relationship to interference control as does ADHD, which might provide clues as to why ADHD and RD co-occurr so often. Because data were analyzed separately for Control/ADHD and RD children, two questions have relevance to understanding the relationship of reading and language to inhibitory control.

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[52] It is notable that these findings do not mirror the exact pattern of results found by Gernsbacher and colleagues (2001) in their college-aged sample of poor comprehenders. Possible reasons for this discrepancy will be discussed later in the Limitations section.

First, is reading related to suppression failures for normal variations in reading ability? Second, is reading related to suppression failures in a language-disordered, RD, sample?

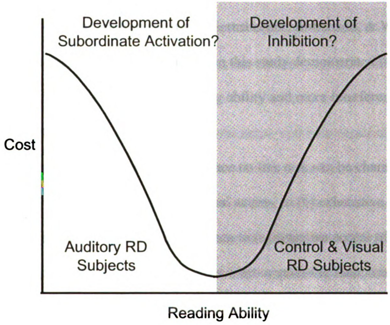
Although findings for children with RD must be regarded as preliminary, their performance on this task offers some information regarding the relationship between reading and inhibitory processes that may be useful in guiding future, larger studies. Note that while the implications of RD findings could be discussed extensively in their own right (e.g., as to their relevance to theories on language comprehension in the cognitive literature), given the secondary nature of these analyses, most of the current discussion will focus on how findings for RD and reading were similar or dissimilar to findings for ADHD and attention problems.

Relationship of Reading and Language to Interference Control

The patterns of effects produced for reading and language abilities were clearly distinct from those related to ADHD/inattention. Overall, when results for RD children on both the auditory and visual task were considered together, these children appeared to demonstrate a U-shaped developmental pattern of interference control on the Ambiguous Words Task (see Figure 7 below). Thus, RD children with both the weakest and strongest reading abilities experienced the most interference from competing cognitive contents, whereas RD children with intermediate levels of reading ability (still impaired relative to others their age), experienced dimensionally *lower* interference than their other RD counterparts. One important caveat regarding interpretation of RD findings is the possibility that differences in task demands inherent to the auditory versus visual version of the task produced differences in response patterns. This possibility will need to be examined further in future studies.

One possibility is that differences in resource allocation are associated with relative differences in reading abilities. Thus, RD children who were the poorest readers appeared to experience difficulty activating the subordinate, less-frequent, meaning of the homonym (likely due to weaker language abilities and vocabulary), which consequently led to greater interference when required to retrieve this meaning over the dominant meaning.[53]

Figure 7. Conceptual Model for the Relationship of Reading Ability to Interference Control in Children with RD and Normal-Reading Controls.[54]



[53] This interpretation is supported by findings of smaller facilitation effects on the auditory task (reported in the appendix) when the less-frequent homonym meaning was primed in both the prime and target sentence (i.e., "Benefits" for sentences presented in the "Same" condition).
[54] Note that this figure depicts a conceptual integration of the positive and negative correlational patterns demonstrated by RD children on the auditory vs. visual task versions and the positive correlation for Control children.

Findings of *reduced* interference for RD children with intermediate reading ability (still impaired relative to others their age in reading), suggested more accessibility to both word meanings than the other RD children, along with a failure to utilize context to constrain competing homonym meanings. Simpson, Krueger, Kang, and Elofson (1994) suggested that such a finding may be attributable to a developmental transition involving greater familiarity with less-frequent homonym meanings but lack of knowledge for dominance hierarchies (i.e., relative frequencies) that results in activation of both meanings.

Higher levels of interference as reading ability becomes stronger suggest utilization of selective access to the context-appropriate homonym meaning (perhaps through an automatic suppression mechanism; Gernsbacher, Robertson, & Werner, 2001). Note that normal, non-ADHD, children in this study demonstrated the same, albeit weaker, association between better reading ability and more interference (i.e., the right side of Figure 8).

Taken together, RD children's performance on this task can be characterized as proceeding from (a) high-frequency-driven lexical access, to (b) exhaustive lexical access for both meanings (regardless of context), and then to (c) selective access of the context-appropriate meaning (producing processing costs when required to then access the context-inappropriate meaning). Since associations between interference and reading ability were not related to absolute reading level (i.e., raw scores) and because Control children showed a similar associational pattern, this finding may reflect differences in resource allocation associated with reading ability (or vice versa) rather than with a specific developmental trajectory.

The right half of the curve shown in Figure 8 is consistent with the findings of Gernsbacher and colleagues' (2001) study of college students (and as noted was also found in Control children in this study). Findings thus partially replicated those of Gernsbacher et al and extended them to a child sample. Given the similar patterns of findings in both children and adults across their study and this one, current findings again may reflect not merely a developmental trajectory towards constrained lexical access but, instead, innate differences in resource allocation in strong versus weak readers. Thus, part of what makes a good reader may be use of suppression to block out irrelevant or competing meanings during comprehension (or more automatic decoding which then frees up resources to direct towards suppression). Current findings of *no* association between absolute reading level (i.e., raw scores rather than age-standardized scores) and interference control suggests that this may be the case (although would certainly not rule out a more subtle developmental effect).

Relationship of Reading and Attention Interaction to Interference Control

How then do findings for interference control in reading relate to those for inattention? First, there was some suggestion that reading ability and attentional control interacted to determine degree of interference control in language comprehension for children with *normal* reading (i.e., Non-RD). Thus, after removing the effects of IQ, the interaction between attention problems and reading ability marginally predicted vulnerability to interference on the Ambiguous Words Task.

The interaction between reading and attention suggested that attention problems mediated the relationship between reading and interference control. Thus, in the absence of attention problems the relationship between reading and interference control for normal readers followed the pattern just discussed (see right side of Figure 8). However, *strong reading ability in the context of high inattention* was associated with *less* interference from competing meanings (i.e., suppression impairments)—similar to that found in poor readers. For good readers, attentional abilities therefore appeared to mediate interference from competing semantic representations, suggesting that effective allocation of attention may in fact play a role in effective text comprehension. Good readers likely have more automatic word decoding, but if they have high levels of inattention they too experience reduced resources to allocate for suppression of irrelevant information (thus performing like poor readers—with or without attentional impairments).

What these findings suggest is that 1) reading ability influences interference control--or vice versa-- and 2) a possible developmental trajectory exists for reading ability and resource allocation in which automatic suppression mechanisms are not utilized until more advanced reading development.[55] *Inattention* influenced interference control independently of reading effects, yet also interacted with them. Note that weaker verbal working memory (on the expressive language task), like high levels of inattention, was also strongly and consistently associated with interference from competing meanings across clinical groups. Like inattention, then, smaller working memory capacity (regardless of clinical diagnosis), was associated with difficulty controlling interference from competing cognitive contents.

[55] Despite no interference findings associated with absolute reading level or age, most children in this sample activated both homonym meanings (as evidenced by mean facilitation in RT from prime to target in all conditions for all groups). Thus, at this developmental stage—with the exception of the best readers—most children (regardless of their clinical diagnosis) may not yet have developed automatic suppression mechanisms that constrain lexical access.

In summary, one possibility suggested by current findings is that suppression failures evidenced by children with ADHD and RD have a different locus. Thus, children with ADHD or individuals with lower working memory capacities may have difficulty resolving interference due to impairments in strategic inhibitory processes that require utilization of context to suppress competition. In contrast, RD children may experience problems with more automatic suppression (which only appear at a more advanced level of reading proficiency—perhaps after the act of decoding and reading attains high enough levels of automaticity—and occurs as a byproduct of lexical selection) or possibly activation (i.e., ability to quickly enhance and retrieve semantic or lexical information), but they do not have difficulty using context to strategically or effortfully suppress activation once it occurs.

Revision of Misinterpretations

Performance on the Garden Path Task examined a second aim of this study: the ability of ADHD and RD children to consciously and effortfully revise or update assumptions when given cues that they had made a misinterpretation. Just as interference control is necessary for individuals to develop and maintain coherent thoughts and ideas and to regulate and direct their behavior (e.g., through internally represented goals), an individual's ability to revise or update assumptions is also crucial to cognition and behavioral regulation, and impairments in this ability would be likely to produce difficulties in social interaction and oppositional behavior (which might actually stem from deficits in cognitive processing rather than "true" oppositionality). Everyone, for example, has moments of speech misperception that produce problems in understanding a speaker's intended meaning. Often in such situations, one realizes the error from the subsequent context of the conversation and is able to revise the initial misinterpretation to produce a coherent understanding of the discourse. In contrast, inability to adapt to these kinds of conversational "updates" would cause an individual to seem perpetually socially "out-of-step"—a common descriptor of ADHD children.

The process of revising misinterpretations differs somewhat from the interference control construct just discussed in that it requires 1) more conscious allocation of resources towards effortful or strategic inhibition and 2) inhibition at the *syntactic* as well as semantic level for correct performance. Thus, unlike the Ambiguous Words Task, performance does not rely merely on overcoming semantic activation. Rather, it requires actually *altering* the syntactic representation (or causal chain) from which the semantic activation and interpretation derives and therefore examines the role of inhibition at a higher level of cognition.

Relationship of Inattention/ADHD Diagnosis to Revision of Misinformation

Comparisons of ADHD and Control children revealed that both groups produced a large number of errors when misled into a semantically plausible sentence misinterpretation (e.g., answering yes when asked, "*Did Joe walk the dog?*" following "*As Joe walked the dog napped.*").[56] However, ADHD children were much less able to utilize semantic implausibility (i.e., seemingly illogical sentence meanings) to overcome misinterpretations arising from syntactic garden paths. Such a finding suggests that Control children utilize effortful, strategic, or executive control to suppress an initial interpretation when given more contextual information to do so (i.e., when the interpretation arising from the garden path cannot be semantically licensed). In contrast,

[56] Recall that even "plausible" sentences produced semantically implausible misinterpretations but that the verb-object relationship was plausible.

higher levels of hyperactivity, inattention and ADHD diagnosis were associated with deficits in these strategic processes and were robust to age and IQ control.

The perseverance of these implausible misinterpretations in children with ADHD was quite remarkable. Thus, children with ADHD continued to maintain misinterpretations under highly illogical circumstances— for instance, answering "yes" when asked, "Did Meg play the shoes?" following the sentence, *As Meg played the shoes got shined.* What's more, it is unlikely that these findings in ADHD children can be attributed to globally decreased effort or to over-reliance on pragmatic inferences (i.e., general reasoning), since to answer "yes" incorrectly to the question, "Did the ape eat the tree?" or "Did Meg play the shoes?" is more illogical and in greater violation of a general reasoning strategy than to answer "no" (which would have been the correct answer). Thus, the most likely explanation for these findings is that failures in strategic suppression mechanisms affect children with ADHD's ability to revise causal relationships (and the resultant interpretations) once they have been established. One important caveat to this interpretation, however, is that—to prevent strategy effects and to encourage effortful processing—*filler* sentences occasionally required "yes" answers to similarly implausible assumptions (*As the girl played the fox her mom left the room. Did the girl play the fox?*). Experimental design might therefore partially account for children with ADHD's decreased sensitivity to semantic implausibility, but does not explain their poorer performance relative to Control children (i.e., Controls *did* benefit from semantic implausibility) nor does it explain their decreased benefit from RAT verbs (i.e., under conditions with a lower revision threshold).

Findings regarding difficulties revising misinterpretations are relevant to the functioning of ADHD children in a multitude of areas. Consider, for example, the ADHD child who gets bumped while standing in line. Such a child, upon receiving an apology and being told that the offense was accidental, would have an exceedingly hard time revising an initial interpretation that he/she had been purposefully pushed and might also fail to benefit from external cues in the environment that might demonstrate that the push had been accidental (e.g., incorporating perceptual information about the other child tripping prior to the bump). These kinds of difficulties in children with ADHD might therefore contribute to the development of hostile attribution biases, a precursor to oppositional defiant or conduct disordered behavior (Crick & Dodge, 1994). Future studies could examine this hypothesis by determining whether deficits in revision of misinterpretations in the language domain are associated with higher levels of oppositional or conduct disorder behaviors.

As well as examining the effect of contextual cues on ADHD children's implementation of strategic suppression, this study also examined whether ADHD children's performance would improve when inhibitory processing demands were reduced (i.e,. for sentences using Reflexive Absolute Transitive [RAT] verbs, which were easier to revise than sentences with Optional Transitive [OT] verbs). For instance, in the RAT-verb sentence, *"As Daddy shaved the cat sat in the tree,"* the relationship between *"shaved"* and *"cat"* should be easier to alter or "delete" than the relationship between "*walked*" and *"dog"* in the OT-verb sentence, "As the man walked the dog napped" (for reasons to be discussed shortly).

Findings revealed that *both* groups of children found it easier to revise misinterpretations when syntactic demands were less complex (e.g., in the *"shaved the cat"* RAT-verb sentence above), but that ADHD children benefited less than Control children (thus continuing to show large inhibition failures). There was some indication that this effect was specific to hyperactivity rather than inattention symptoms, suggesting that more severe deficits in effortful inhibition might underlie this finding. Alternatively, as with findings for the Ambiguous Words Task, inattention may have been the primary factor associated with difficulty in revision of misinterpretations (i.e., interference control), but high levels of hyperactivity may have been related to decreased processing *effort* (e.g., more superficial processing of sentences), leading to continued inhibition failures even when syntactic and inhibitory demands were reduced (as in the RAT sentences).

One interpretation for why *all* children improved their performance on RAT garden path sentences (despite the lesser benefit for ADHD compared to Control children), is that improved performance may reflect the relatively greater ease with which the inappropriate interpretation (i.e., verb-noun thematic role assignment) can be overcome or "deleted" when either a) the subordinate verb is more weakly connected to the object (perhaps through competition from the implicit object [i.e., himself/herself] during syntactic parsing) or b) when the incorrect thematic role assignment is not necessary to maintain the causal structure of the sentence—perhaps because the initial thematic role assignment can be *replaced* with an implicit reflexive object (herself/himself)[57] For example, consider again the sentence, *"As Daddy shaved the cat*

[57] Since "plausible" condition sentences continued to produce implausible misinterpretations (e.g., *As Betty woke up Daddy was sleeping in the den.*). Thus, effortful and semantically-driven inhibitory mechanisms

sat in the tree." It might be possible to delete the association between *"shaved"* and *"cat"* by altering the sentence to *"As Daddy shaved [himself] the cat sat in the tree."*

Taken together, then, current findings suggest that: 1) Children with ADHD are less successful than Control children in using either implausibility or RAT verbs to revise garden path misinterpretations; and 2) the locus of these revision failures may relate to ineffectiveness of effortful or strategic inhibition, such that ADHD children find it difficult to "delete" incorrect thematic role assignments or to revise verb argument structures in conditions in which Control children can do so.[58] These findings thus replicate many of the findings from the Ambiguous Words task and suggest a consistent relationship between inattention, weaker cognitive inhibition, and poorer language processing. Findings on the Garden Path Task additionally suggested that hyperactivity might—not surprisingly—be associated with decreased processing *effort* under more difficult or more complex processing conditions (leading to continued inhibitory deficits even under conditions with reduced processing demands).

These findings have broader implications in the context of language comprehension or reading comprehension deficits in ADHD, as well as for possible methods of remediating these difficulties. With regard to the more global implications for the effects of inhibitory deficits in language comprehension, Johnson and Seifert (1994) examined the persistence in memory of inferences based upon corrected

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could still be drawn upon. In contrast, Christianson et al.'s study, which had a condition that induced truly plausible misinterpretations—e.g., *As Betty woke up Daddy stretched his arms.*—showed continued garden path effects for plausible RAT verb sentences that were similar to those found for OT verbs (contrary to current findings).

[58] An alternative interpretation might be that RAT inhibition involves a non-effortful process—perhaps more syntactically and automatically driven-- and ADHD children then don't receive any additional benefit from contextual-level inhibition. This interpretation does not fit with the fact that ADHD children clearly receive *some* benefit from contextual level inhibitory processes (these are just not as large as for Control children).

misinformation during comprehension of "garden path passages" (i.e., passages that presented misinformation, which was later corrected). Consistent with current findings, misinformation was maintained in passage memory when it afforded causal structure to the inference (e.g., when a character mentioned as a crime suspect is later said to have been cleared of wrong-doing but no new suspect is named). This effect was mitigated, but still persisted, when the misinformation was replaced by other causal information, rather than when it was merely negated (for instance, when the initial crime suspect is absolved of the crime and a new perpetrator is named).

Clearly, then, impairments in strategic inhibitory mechanisms that affect language comprehension would have wide-spread implications for general functioning. At the minutest level, such difficulties would seriously impact ability to draw correct inferences (i.e., meanings/conclusions) from both written and spoken language and might also contribute to problems with language *production* (e.g., to processing disfluencies in natural speech). At a more global level, social interaction and communication would, perhaps, be most affected, due to their fluidity and constant demands for "on-line" accommodation to the communications of others. As mentioned earlier, such impairments would also have direct implications for drawing accurate conclusions about others' behavior (e.g., incorporating the contextual information about the boy tripping to understand that his pushing you was not intentional) and for updating and changing one's conclusions when new information becomes available. Functional impairments in these processes put a child with ADHD at- risk for a host of other problems, including development of hostile attribution biases associated with Oppositional Defiant and Conduct Disorders (as mentioned earlier; Crick & Dodge, 1994) and school failure, and could also explain many ADHD-related executive functioning deficits (e.g., in self-monitoring). With regard to implications for remediation, these findings suggest that children with ADHD should be taught to question their interpretations about events and to search for possible "replacement" information (e.g., the information about the boy tripping) that might help them to revise incorrect interpretations.

Discussion now moves to findings regarding the role of reading and language to revision of garden path misinterpretations.

Relationship of Reading and Language to Revision of Misinformation

Overall, as on the Ambiguous Words Task, the pattern of results in RD children on the Garden Path Task showed striking similarity to the overall ADHD pattern, but appeared to derive from different core deficits. For the most part, reading achievement per se was not related to effortful suppression on the Garden Path Task. However, broad estimates of language abilities and RD diagnosis *were* related to suppression failures and to difficulties revising misinterpretations.

Like findings in ADHD, language problems/RD diagnosis was associated with poorer ability to utilize effortful inhibitory control to suppress an initial misinterpretation. Thus, RD children were much less able to utilize semantic implausibility (i.e., seemingly illogical sentence meanings) to overcome misinterpretations arising from syntactic garden paths. Such a finding suggests failures in utilization of effortful inhibitory control to suppress an initial interpretation when given increased incentive to do so (i.e., when the interpretation arising from the garden path cannot be semantically licensed). Also like ADHD children, RD children benefited less from reduced syntactic demands (i.e., RAT verb manipulation) in revision of misinterpretations (thus continuing to show large garden path effects).

However, RD children demonstrated two important differences in their performance from ADHD children. First, RD children were more sensitive to the effects of *plausible* verb-object relationships in garden path conditions (regardless of verb type) than Control children (something that was not true of the ADHD group). Consequently, they were more vulnerable to being misled into a garden path misinterpretation when the verb-object relationship was plausible (e.g., *"the ape ate"*). Such a difference may suggest that underlying language-related difficulties in processing complex syntax leads to a concomitant reliance on a more piece-meal, general pragmatic reasoning strategy that is based on analysis of verb-object relationships to aid comprehension. This interpretation is supported by a second primary difference between the performance of ADHD and RD children: increased sensitivity to *implausibility* in comprehension of *non-garden* path control sentences. Thus, RD children were able to "recoup" their prior impairments when they could rely on a general pragmatic inference reasoning strategy (based on verb-object implausibility) afforded by non-complex or misleading syntax.[59]

Taken together, then, RD and language findings are associated with 1) reduced benefit from implausibility in correcting garden path misinterpretations, suggestive of impairments in effortful or strategic inhibition, like ADHD, and 2) increased vulnerability to being misled by semantically plausible misinterpretations, reflecting a possible reliance on more piece-meal, general pragmatic inferencing strategies (e.g., regarding verb-object relationships) under conditions requiring comprehension of

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[59] Note that dimensional analyses found similar findings related to inattention, however these results did not hold during categorical group analyses, so may not have been specific to ADHD.

complex syntax, and 3) *increased* reliance on contextual cues (e.g., semantic implausibility vs. plausibility) to compensate for language processing weaknesses.

Conclusions and Preliminary Interpretations.

Taken together, findings for ADHD and RD children provide some preliminary ideas regarding the co-occurrence of the two disorders. Failure to effectively utilize semantic information to recover from garden path misinterpretations was the primary finding associated with both inattention and reading problems on this task. Both ADHD and RD children thus exhibited impairments in effortful inhibitory control on this task. However, RD children also seemed to have more generalized problems parsing and comprehending complex syntax (i.e., they were more vulnerable to making garden path misinterpretations) and seemed to rely more heavily on semantic implausibility and pragmatic inferencing to help them compensate for these difficulties. Thus, one possibility is that RD children had to allocate more resources to syntactic parsing and analysis, leaving fewer resources to suppress and revise misinterpretations. Such an interpretation, if borne out in future studies, would suggest that RD children are more likely to exhibit inhibition impairments when their processing resources are taxed by more lower-order language deficits. Such processing capacity "overloads" would cause them frequently to demonstrate behavior that looks inattentive or to produce problems with planning and organization analogous to those found in ADHD. As a final element to discussion of current findings, further consideration will now be given to findings regarding the overlap of ADHD and RD in the current sample and to a proposed theory for their co-occurrence.

Integration and Proposed Theory for the Co-Occurrence of ADHD and RD

Co-Occurrence of Inattention and Reading Problems

At a behavioral or phenotypic level of analysis, those with high levels of inattention were at risk for reading problems. Thus, with the stringent diagnostic criteria employed in this community-recruited sample, 17% of ADHD children also met criteria for RD. This comorbidity rate was lower than many prior studies but still far above chance. Children with ADHD-I were more than twice as likely to meet criteria for RD as children with ADHD-C (30% vs. 13%, respectively). Moreover, ADHD children *without* an RD diagnosis had poorer reading comprehension than did Control children, although groups did not differ in basic reading skills (e.g., word recognition, spelling, and phonological decoding) or language abilities.

Findings also supported high rates of inattention in those with reading problems. Thus, 35% of RD children also met criteria for ADHD, with approximately equal co-occurrence rates for ADHD-C versus ADHD-I (20% vs. 15%, respectively). "Pure" RD children (i.e., those *without* an ADHD diagnosis) also had much higher levels of inattention than did Control children (on average, 5 of 9 DSM-IV inattention symptoms).

Proposed Theory for Future Study

Taken together, then, expected ADHD-RD group distinctions (e.g., in behavioral hyperactivity and lower-order reading and language skills) underscored the etiological independence of the two disorders. They were also distinguished by a clearly different pattern on some types of interference control measures in this study. However, findings also revealed possible reasons for the frequent behavioral phenotypic overlap between ADHD and RD. What emerged was the possibility that inhibitory impairments may produce problems with higher-order language processes in ADHD children. Likewise, lower-order language problems (e.g., in phonological processing) may tax the cognitive resources of children with RD, producing impairments in inhibition-reliant language processes and secondary attention problems.

One primary contribution of this study is that it highlights the fact that different core deficits in ADHD and RD can also lead to similar cognitive outcomes (or secondary) deficits. What remains to be answered is whether these core deficits themselves can actually *produce* the other disorder (rather than common secondary symptoms). Although this current study cannot directly answer this question, it is interesting to speculate about pathways by which such comorbidity of ADHD and RD could occur.

Pathway from ADHD to RD

With regard to a possible pathway from *ADHD to RD* co-occurrence, attention problems in ADHD might create working memory/capacity limitations that—combined with even weak phonological processing or phonological awareness skills—could cause significant problems with phonological decoding and manipulation of phonemes. If so, ADHD children should show increased phonological decoding deficits as working memory/effortful processing demands increase but have no problems with easier phonological awareness tasks. It should also be possible to see dimensional differences in phoneme awareness in ADHD children, with the tendency for RD diagnosis to increase as phoneme awareness skills decline. One other possibility is that children with ADHD spend less time engaged in language or reading-related activities (due to their attentional difficulties), and this lack of "experience" or practice with language (which would prevent development of greater automaticity in language functions) leads to requirements for more effortful processing which children with ADHD are unable to deploy because of their inhibition deficits. As a result, inhibition and decreased language facility would interact directly without the need to posit working memory impairments as an intermediary (MacDonald & Christiansen, 2002).

If all of these factors were borne out, one might expect that ADHD children would have a reduced threshold for developing RD, such that weaknesses in phonological awareness (which are believed in the empirical literature to occur along a continuum)—even if not as severe as those found in "pure RD"—and their interaction with the severity of attentional impairments could produce a true reading disorder or dyslexia in ADHD individuals. Future studies can test these hypotheses by using more sophisticated measures of phonological processing (Fitch, Miller, & Tallal, 1997) and examining whether the performance of ADHD children changes according to working memory and effortful processing demands. It may also be interesting to examine these processes in much younger children who are just beginning to develop reading in order to gain clues as to developmental trajectories.

Pathway from RD to ADHD

Could a similar pathway lead *from RD to ADHD*? Current findings suggest that inhibition and suppression deficits in RD children might occur only on language-mediated or perhaps also temporal processing tasks (Fitch, Miller, & Tallal, 1997)).[60] In this scenario, RD children may experience capacity or resource limitations during

[60] Assuming that RD doesn't also involve generalized problems with automaticity and sequencing that are not solely language-dependent. In the cognitive literature on RD deficits, this debate has not yet been resolved

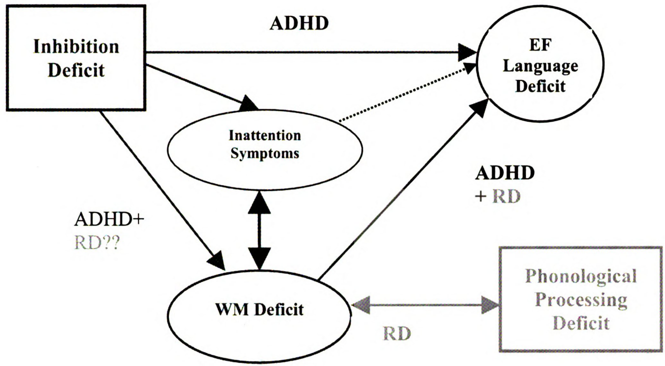
language processing that would be manifested in secondary deficits in effortful processing and inhibition and might not be expected to occur when language processing was not required. Thus, behavioral diagnosis of ADHD might be made due to the *secondary* manifestations of attention and organization problems that—rather than deriving from a primary attentional or inhibition deficit—arise from lower-level language processing impairments (e.g., phonological decoding) that produces resource limitations. If that is the case, then this pathway would produce real inhibition and attentional impairments in children with RD but *only* under specific processing conditions (e.g., language-dependent tasks) and would therefore not be a "true ADHD"—i.e., would not involve a core inhibition impairment.

Most studies finding inhibition deficits in RD children have utilized tasks with language demands (e.g., CPT's and Logan's Stop Task—both of which require speeded and automatic processing of letters; Purvis & Tannock, 2000; Willcutt et al., 2001; Nigg, 1999). Only one known study has examined response inhibition in RD children using nonverbal stimuli, and this study produced equivocal results (Moores & Andrade, 2000). To determine whether RD children demonstrate primary inhibition deficits independent of those produced by language processing weakness, future studies should further examine these processes using nonverbal tasks (e.g., antisaccade or covert orienting tasks).

Summary

These independent pathways can be summarized and integrated in the following ways (see Figure 8 below). Increased effort required for word decoding in individuals with reading problems likely leads to resource limitations (i.e., reduced processing capacity or "bottlenecks") in other areas. For instance, increased effort applied towards reading decoding would leave less available resources for reading comprehension and would also limit the available working memory "space" for such additional operations (e.g., creating and holding a coherent semantic and representational structure, per Gernsbacher's (1997) Structure Building Framework). Children with ADHD, in contrast, experience these resource limitations directly from their attentional/inhibitory deficits which would also limit the size of working memory space and could produce processing bottlenecks and interference with efficient language comprehension or reading comprehension. Thus, both groups do experience true suppression failures, despite the fact that the origin of their suppression

Figure 8. Theoretical Model of Possible Pathways from ADHD to RD and RD to ADHD.



deficits differ. Both groups also experience end difficulties in language processing despite the fact that they derive from different sources.

Given that reading deficits in dyslexia do not occur in a vacuum (i.e., additional cognitive deficits—particularly in phonemic awareness—underlie these reading problems), it is also important to consider the role played by inhibition in language development and the manner through which inhibition impairments might then affect reading development. One possibility is that deficits in phonemic awareness and phonological processing could lead to problems in orthographic decoding—*at least in part—via* inhibition failures.

In children with RD, difficulties deciphering phonemes auditorily may lead to a general lack of knowledge about the properties of phonemes in speech and about how they combine to form words. Developmentally, this difficulty might then lead to increased processing requirements/effort needed for the *linguistic* aspects of language processing and result in limited resources available for other higher-order cognitive processes like learning and storing phoneme-grapheme correspondences, orthographic decoding, development of automatic word recognition, and reading comprehension (Crain & Shankweiler, 1988; Shankweiler et al., 1999). Later in development these resource limitations may appear as frank inhibition impairments, as children with RD will have limited resources to utilize for other higher-level cognitive language processes (*not just related to reading*) such as interference control. Some support for this assertion is found even for dyslexic adults in the neuroimaging literature. Brunswick, McCrory, Price, Frith, & Frith (1999), for example, reported that college students with RD demonstrated reduced activation in left posterior inferior cortex and increased activation in a pre-motor region of Broca's area while reading pseudowords, despite similar accuracy to non-impaired comparison students. The authors attributed this result to problems with highly automated aspects of reading (specifically, lexical retrieval) and an associated increased need for effortful compensatory strategies.

Similar processes might also lead to language and reading problems in individuals with core inhibition deficits. For instance, inhibition deficits also lead to cognitive resource limitations that might make it hard to hold and manipulate phonemes when decoding an orthographic representation (even in the absence of diminished knowledge about phoneme-grapheme correspondences or linguistic properties of words), leading later in development to poorer word decoding, failures in automatic retrieval, and deficits in reading comprehension—despite adequate underlying language abilities.

Limitations

A number of limitations inherent to the current study must be considered.

Ambiguous Words Task

The locus of inhibition impairments for ADHD children on the Ambiguous Words Task differed from those predicted by Gernsbacher, Robertson, and Werner's findings (2001) upon which the current study was based. Several factors are important in considering this discrepancy, including specific aspects of task construction, variability among studies in the lexical ambiguity literature regarding what pattern should be "expected," and the possibility of developmental effects.

This study used only pairs of dominant-frequency prime stimuli with subordinate-frequency target stimuli. In hindsight, using these polarized homonyms produced a series of confounds for interpreting results. Simpson and Adamopoulos (2001), for instance, suggested that inhibition may not be required for processing dominant-meaning homonyms when the homonym occurs late in a sentence (i.e., after the biasing context, as occurred here), because there is relatively little competition between meanings. Dixon and Twilley (1999) also argued that lexical ambiguity resolution is a function of both bottom-up stimulus driven frequency activation effects and top-down contextual inhibition effects, with inhibitory mechanisms playing less of a role in access to high frequency homonym meanings.

These studies therefore suggest that the dominant prime/subordinate target stimuli used in the current study, as well as the possibility of stronger contextual biases of current sentences, might produce different patterns of effects than those found by Gernsbacher et al.[61] Processing of "nonsense-meaning" primes also created problems for children in this study and confounded measurements of "Cost" from a neutral baseline. To measure inhibition effects confidently, in future it may be better to use balanced-frequency homonyms and to compare them to truly neutral meaning prime sentences (e.g., *She threw the spade).* As pertains to current findings, it seems possible that—rather than measuring automatic suppression that occurs as a byproduct of prime activation—the current study measured somewhat more effortful interference control abilities. Thus, it seems likely that the current task continued to measure inhibition in these children, but not in the way initially anticipated.

An additional confound—at least for directly comparing effects between the present study and those of Gernsbacher et. al.—concerns likely developmental differences between adults and children in mechanisms of lexical ambiguity resolution.

[61] Note, however, that Gernsbacher, Robertson, and Werner (2001) did utilize a dominant prime and subordinate target condition and found no differences in the overall pattern of results versus their other experimental manipulations.

Prior studies in the cognitive literature have revealed that, on the one hand, 2nd and 4th grade children have unconstrained lexical access in the absence of a biasing context (e.g., they show continued facilitation for both dominant and subordinate homonym meanings even after a 2000 msec delay), whereas older children inhibit the less-frequent meaning (Simpson & Foster, 1986; Simpson & Lorsbach, 1983). Other evidence suggests that younger children (5th grade or younger) rely more heavily on sentence-level semantic context to constrain lexical access than do older, 12-year-old, children (who rely more heavily on frequency to determine lexical access). In fact, Simspon and colleagues (1994), reported a "U-shaped" developmental curve for development of lexical ambiguity that was similar to the one reported here. Taken together, then, current findings appear consistent with the literature on lexical ambiguity resolution, despite their difference from those of Gernsbacher and colleagues.

Finally, perhaps the most important limitation and qualification to current findings for the Ambiguous Words Task must include an acknowledgement that a role for inhibitory mechanisms in language processing is far from established in the cognitive literature. Thus, it is impossible to rule out activation-decay or parallel distributed processing model explanations of ambiguity resolution and interference control (MacLeod, 1991). Put another way, interference findings for ADHD and RD children on this task could also reflect differences in relative activations of competing homonym meanings, differences in the time-course of decay, and the occurrence of processing bottle-necks that do not stem from inhibition impairments.

Garden Path Task

Overall, findings on the Garden Path Task were not subject to many of the methodological and developmental confounds that occurred in the Ambiguous Words Task. Thus, overall, children in this study responded very similarly to Christianson et al.'s (2001) college-aged sample. Current findings do, however, merit one important caveat. This task is a very difficult one—even for normally functioning young adults—and likely relies upon many cognitive processes for successful performance (not just inhibitory processes). Both ADHD and RD children demonstrated a strong reliance on inferential and pragmatic reasoning strategies (i.e., the plausibility of verb-object relationships). Consequently, it is important to consider the possibility that current findings result, not from true inhibition impairments, but from generalized factors associated with task difficulty. In this light, ADHD and RD differences among different conditions may stem simply from the fact that these experimental manipulations made the task easier. If this is the case, then current findings may actually result from non-specific variation in task difficulty and to over-reliance on inferential processing to compensate for these difficulties, rather than from specific inhibitory deficits.

Paradoxically, contrary to potential problems with task difficulty for ADHD and RD children, garden path manipulations were too easy for Control children, causing performance in a number of conditions to reach ceiling levels. Due to these ceiling effects, it was difficult to determine whether some of the significant effects resulted from true group differences or from an artificial limitation in range for higher-functioning subjects.

Additional Considerations

A number of broader methodological limitations are relevant to the study. One obvious limitation was the use of both a visual and auditory task version which makes all comparisons to RD children who received the auditory task of questionable generalizability. In addition, from a statistical standpoint, the very large number of analyses performed in this study increases the likelihood that some findings are the result of Type I error. High variability in performance for all groups (evidenced by large standard deviations) made it difficult to detect group differences. Furthermore, unequal group sizes raise the possibility that some effects may have been under- or over-estimated. The use of mathematical corrections to control for task inconsistencies (such as the "corrected Cost" score computed in the Ambiguous Words Task) may also have altered the validity of current findings.

One final limitation concerns this study's small sample size. This limitation was particularly true as it pertained to the number of ADHD girls and limits the generalizability of the gender effect on the Ambiguous Words Task. Small sample size also prevented analysis of age-group differences. Given the wide age-range used in this study (ages 8-14), it would have been preferable to have divided children into groups of younger and older children, thereby allowing for a more systematic exploration of developmental effects. It is also relevant to note that the *average* age of this sample was actually younger than was ideal (average age in all groups was 10), making it possible that these children hadn't fully developed the inhibitory mechanisms that were being explored (Harnishfeger, 1995).

Conclusions

Despite these limitations, the current study breaks new ground in at least two important ways. One, it shows that cognitive tasks of inhibitory language processing can be adapted for use in a child population and are sensitive to differences in inhibitory functioning. Two, this study provided new findings regarding language processing problems in children with ADHD that are related to inhibitory control mechanisms previously identified for motor control. Importantly, in contrast to null findings in many previous studies of cognitive inhibition in ADHD, the current study indicated that these impairments can be detected in higher-order language processing in these children. Thus, null findings in prior studies of interference control and cognitive suppression could reflect the modality in which suppression is being measured (e.g., perceptual, motor, or language), the level to which attentional selection is directed (e.g., Balota, Cortese, & Wenke, 2001), and the requirements for top-down, effortful, and semantically-driven processing. Finally, similarities in ADHD and RD deficits suggest areas for future study that may explain the disorders' high rates of co-occurrence.

APPENDIX A

Demographics and Group Descriptions

Inattention and Hyperactivity Symptoms

Inattention

The interaction between ADHD group and RD group was significant for total number of inattention symptoms by the "OR" diagnostic algorithm [$\underline{F}(2, 76)=10.74$, $\underline{p}<.001$]. As expected, children with ADHD-C and ADHD-I had more symptoms of inattention (regardless of their RD status) than did Control and pure RD children [ADHD main effect: $F(2, 76)=89.87$, $p<.001$]. Also consistent with prior findings in RD samples, RD children *without* a diagnosis of ADHD had more symptoms of inattention than did Control children [RD main effect: $F(1,76)=11.30$, $p=.001$]. This effect held even after excluding the five RD children who had met criteria for situational or subthreshold ADHD [$F(1,32)=10.67$, $p<.01$, mean RD inattention symptoms: 2.3 ± 1.9]. Similar patterns of results were found in comparisons of DISC Inattention symptoms (i.e., only parent-rated inattention symptoms; refer to main text) and maternal and teacher behavioral ratings of inattention (Table 33).

Hyperactivity

There was no significant interaction between ADHD and RD group for hyperactivity symptoms [$F(2,76)=0.03$], nor was there a significant main effect of RD group [$F(1,76)=0.47$]. As shown in Table 2, both ADHD-C and ADHD-I children had more symptoms of hyperactivity than non-ADHD children [$F(2,76)=122.93$, $p<.001$] and, as expected, ADHD-C children had higher levels of hyperactivity than ADHD-I children.

Teacher ratings, shown in Table 33, did not support higher levels of hyperactivity in ADHD-I or RD children versus control children.

Oppositional, Aggressive, and Conduct Disorder Symptoms

ADHD-C and ADHD-I children had higher rates of Oppositional Defiant Disorder (ODD) (see Table 2). Children with RD also had marginally higher rates of ODD than Control children, although this higher incidence of ODD was accounted for entirely by those RD children with high levels of situational ADHD symptomatology (by mother report on the DISC). The rates of Conduct Disorder (CD) in the sample did not significantly differ among any of the key diagnostic groups.

As seen in Table 33, similar results were obtained for maternal behavioral ratings of aggressive and oppositional behavior. Teacher behavioral ratings supported increased levels of oppositional, aggressive, and conduct problem behaviors in children with ADHD-C but not in ADHD-I or RD (Table 33).

Anxiety and Depression Symptoms

Differences among groups on maternal and teacher behavioral ratings of anxiety and depression are shown in Table 33. Children with ADHD-C and ADHD-I had high levels of depression compared to Control children, while children with RD also had more depressive symptomatology than did Control children. With regard to maternal ratings of anxiety, both ADHD-C and RD children had higher levels of anxiety than did the other groups. The interaction between ADHD and RD groups [$F(2,76)=2.11$, $p=.13$] showed a trend suggestive of higher levels of anxiety in RD children with comorbid ADHD. Analyses on teacher ratings of anxiety and depression indicated significantly higher levels of anxiety and depression in ADHD-C versus control children (Table 33).

Table 33 Mean Parent Behavioral Ratings by Group (T-Scores).

	Control N=27	ADHD-Only		RD-Only N=13	RD+ADHD	
		Combined N=28	Inattentive N=7		ADHD-C N=4	ADHD-I N=3
BASC Attention Problems						
Mother	47.5 (5.5)	66.0 (7.9) ^{A}	71.8 (6.6) ^{A}	59.9 (15.3) ^{A}	75.5 (7.6)	70.0 (5.7)
Teacher	44.3 (5.6)	65.2 (7.6) ^{AG}	61.0 (10.8) ^{B}	58.5 (11.2) ^{B}	71.3 (4.2)	76.0 (5.6)
Conners Hyperactivity						
Mother	48.5 (5.2)	74.0 (11.9) ^{ACE}	61.3 (14.7) ^{A}	57.5 (11.8) ^{B}	78.5 (10.0)	59.3 (4.5)
Teacher	48.6 (5.9)	69.6 (12.6) ^{ACE}	50.6 (10.9)	56.2 (13.8)	70.5 (11.8)	55.3 (11.6)
BASC Hyperactivity						
Mother	44.2 (7.6)	67.7 (13.1) ^{ACE}	54.7 (19.6) ^{B}	48.9 (10.9)	78.3 (14.7)	50.0 (7.0)
Teacher	46.2 (7.6)	65.2 (12.6) ^{ACE}	51.3 (17.8)	52.0 (5.6)	71.0 (11.3)	52.0 (11.8)
Conners ADHD Index						
Mother	47.6 (4.0)	73.3 (10.5) ^{A}	72.9 (12.4) ^{A}	64.9 (14.6) ^{A}	83.0 (5.0)	69.7 (13.4)
Teacher	47.0 (5.2)	72.4 (10.2) ^{ACE}	55.0 (9.4)	58.3 (12.5) ^{B}	77.5 (9.0)	72.7 (14.6)
Conners Oppositional						
Mother	49.5 (7.2)	66.2 (14.3) ^{AC}	61.0 (15.6) ^{B}	55.2 (9.3) ^{B}	80.3 (8.6)	54.0 (11.5)
Teacher	48.0 (4.4)	63.9 (17.7) ^{ACE}	48.3 (2.9)	48.7 (4.7)	62.8 (12.7)	55.0 (11.8)
BASC Aggression						
Mother	45.7 (6.4)	62.2 (14.8) ^{AC}	55.9 (17.9) ^{B}	49.8 (8.3)	68.3 (26.1)	45.3 (8.4)
Teacher	46.4 (4.4)	61.3 (17.0) ^{ACF}	49.0 (9.0)	47.5 (3.4)	68.0 (12.3)	50.3 (11.1)
BASC Conduct Problems						
Mother	45.5 (8.6)	60.3 (20.9) ^{A}	55.7 (17.3) ^{B}	51.5 (7.4) ^{B}	66.8 (27.2)	51.0 (7.8)
Teacher	48.0 (4.9)	57.9 (16.1) ^{BFG}	52.3 (9.5)	51.6 (6.5)	57.7 (14.4)	55.3 (11.4)
BASC Anxiety						
Mother	50.1 (8.1)	55.0 (12.5)	50.2 (11.8)	53.0 (10.2)	69.3 (12.3)	57.7 (20.0)
Teacher	46.6 (7.2)	54.9 (11.5) ^{B}	52.2 (16.0)	51.5 (6.4) ^{D}	45.3 (3.5)	59.0 (17.8)
BASC Depression						
Mother	45.8 (7.7)	61.9 (17.7) ^{A}	62.5 (12.5) ^{B}	55.2 (13.8) ^{D}	69.3 (19.9)	54.3 (11.0)
Teacher	44.9 (4.3)	58.2 (15.2) ^{AFG}	46.2 (7.6)	47.3 (4.4)	55.3 (11.0)	43.0 (3.0)

^{A} significantly different from Control ($p \leq .001$); ^{B} significantly different from Control ($p < .05$); ^{C} significantly different from RD ($p < .05$); ^{D} marginally significant difference from Control ($p < .10$); ^{E} significantly different from ADHD-I ($p < .05$), ^{F} marginally significant difference from ADHD-I ($p < .10$), ^{G} marginally significant difference from RD.

Achievement, Language, and Learning

Reading Achievement

Group means on tasks of reading achievement, language, and learning are displayed in Table 4. Differences among groups for reading achievement measures were explored using a 3x2 univariate ANOVA with ADHD group (Control, ADHD-C, ADHD-I) and RD group (yes, no) as the between subjects variables. Regardless of their ADHD classification (i.e., Control, ADHD-C, ADHD-I), children with RD had lower word recognition (mean: 80.2 ± 9.4; [$F(1, 76)=33.08$, $p<.001$]), spelling (mean: 77.7 ± 9.2; $F(1,76)=29.26$, $p<.001$), phonological decoding (mean: 79.9 ± 10.0; $F(1,76)=21.64$, $p<.001$), and reading comprehension (mean: 87.5 ± 11.7, $F(1,76)=15.80$, $p<.001$) scores.

There were no significant ADHD x RD group interactions on any reading achievement measures. Thus, ADHD-C and ADHD-I children did not differ from Control children in word recognition, spelling, or phonological decoding achievement. The reading comprehension of ADHD-C children was, however, significantly weaker than Control children's and significantly better than RD children's, consistent with expectations of some impairment in academic achievement secondary to ADHD. Children with comorbid ADHD+RD--not surprisingly-- performed like pure RD children on these measures.

Language and Learning

Receptive and Expressive Language. The 3 (ADHD group) x 2 (RD group) ANOVA examining performance on a broad measure of receptive language (CELF Concepts and Directions) yielded no interaction between ADHD and RD group [$F(2,76)=0.83$]. Although the main effect of RD group was significant [$F(1, 76)=4.60$, p<.04], further post-hoc analyses revealed that *pure* RD children did *not* have lower scores on this measure than Control children [F(1,38)=0.61; See Table 4]. Rather, the RD main effect was accounted for primarily by RD children with comorbid ADHD, and the performance of these children was significantly worse than that of pure RD children [F(1,32)=5.24, p<.03].

On the broad measure of expressive language (CELF Recalling Sentences), scores for RD children were significantly lower than scores for non-RD children [F(1, 76)=5.34, p<.03] and, in this case, both pure RD and comorbid RD+ADHD children significantly differed from control children [Pure RD: F(1,38)=6.85, p<.02; RD+ADHD: F(1,32)=5.15, p=.03].

Ratings of Learning Problems. As expected, children with RD had a history of more developmental indicators of difficulties learning to read (maternally-rated on the Learning and Behavior Questionnaire) than those without RD [F(1,76)=29.43, p<.001]. The severity of this history did not differ between comorbid RD+ADHD and pure RD children.

Children with ADHD did not, as a group, have a history of more developmental reading problems [F(2,76)=1.20], and there was no significant interaction between ADHD and RD groups [F(2,76)=0.28]. However, children with ADHD-I (with no diagnosis of RD) were reported to have a greater history of developmental indicators of problems learning to read than did Control children. The severity of these problems was intermediate between children with pure RD and control children.

With regard to teacher ratings of *current* learning problems on the BASC Learning Problems scale, the ADHD and RD group main effects were both significant

[ADHD: $F(2, 76)=5.44$, $p<.01$; RD: $F(1,76)=23.43$, $p<.001$], but there was no significant interaction between ADHD and RD group [$F(2,76)=0.70$]. ADHD and RD children did not significantly differ in teacher-rated learning problems. Qualitatively, as shown in Table 4, comorbid ADHD+RD children appeared to have higher levels of current learning problems.

Note about Classification of Pure RD Children

Despite the very small N's, compared to RD children whose parents did not report clinically significant attentional problems, RD children with situational ADHD had significantly poorer performance on a broad measure of receptive language [$F(1,11)=6.70$, $p<.03$, $\eta^2=.38$] (but not on a broad measure of expressive language [$F(1,11)=0.30$]). These children also had non-significant trends for poorer reading ($\eta^2=.12$), spelling ($\eta^2=.07$), phonological decoding ($\eta^2=.18$), and reading comprehension ($\eta^2=.11$; see Table 34). Children with RD and situational ADHD additionally had marginally significantly more severe developmental histories of reading problems on the Learning and Behavior Questionnaire compared to RD children without such inattention problems [$F(1,11)=4.23$, $p<.07$, $\eta^2=.28$]. Differences in IQ were not statistically significant [$F(1, 11)=0.53$, $\eta^2=.05$] and the effect sizes for IQ differences were much smaller than achievement differences.

Taken together, these results suggest that the RD children with clinically significant attention problems by mother report had more severe impairments in reading and language than did children without such mother-rated attention problems. Given the significant findings on the measure of receptive language, these children may have more severe (or more global) receptive language impairments. Due to these patterns of more severe reading and receptive language impairment in RD children with situational ADHD, but no differences in the severity of teacher-rated attentional problems [$F(1,11)=0.31$, $\eta^2=.03$], these children were included in the pure RD group.

Table 34 Comparison of RD children with and without situational inattention.

		RD+ADHD Inattentive-Situational N=5	**RD** (no inattention) N=8
BASC Attention Problems T-Score	**Mother**	72.0 (6.4)	52.3 (14.3)
Teacher		55.3 (3.1)	60.4 (14.2)
Conners ADHD Index T-score	**Mother**	73.6 (8.9)	59.4 (15.3)
Teacher		55.7 (5.1)	59.7 (15.3)
Estimated Full Scale IQ		99.4 (16.0)	106.1 (16.5)
WIAT Reading (standard score)		75.6 (8.6)	81.8 (9.2)
WIAT Spelling (standard score)		75.0 (5.8)	80.5 (12.0)
WJ-R Word Attack (standard score)		73.8 (12.5)	83.8 (8.3)
WJ-R Passage Comprehension (standard score)		81.6 (9.1)	90.8 (15.7)
CELF-3 Concepts and Directions (scaled score)		7.4 (2.3)^A	10.8 (2.3)^A
CELF-3 Recalling Sentences (scaled score)		7.8 (4.3)	8.8 (2.8)
Average Achievement (Reading, Spelling, and Word Attack)		74.8 (7.9)	81.7 (9.2)
IQ-Average Achievement Discrepancy (SS)		24.6 (17.4)	24.6 (10.7)
Teacher BASC Learning Problems T-Score		60.5 (4.2)	65.0 (14.5)
Learning and Behavior Questionnaire (Total)		33.6 (4.7)^B	25.8 (7.6)^B
LBQ (average score: 0-5)		4.2 (0.6)	3.4 (1.0)

NOTE: Matching letters within a row are significantly different from each other.
$^A p<.05$, $^B p<.07$

Ambiguous Words Task

Preliminary Data Checks

Task Validity

Overall, the task performed as predicted. Thus, children produced more errors to targets in the Different condition, suggesting that the manipulation to test inhibition worked as expected. Error rates also decreased from prime to target in the Same condition, providing evidence that the facilitation manipulation also worked as expected.

Item Analysis

Individual items were examined to determine whether failure rates on any prime sentences were particularly high (and therefore represented bad items). For prime sentences, all items were responded to with better than 60% accuracy. Of 85 prime sentences, 2 Nonsense, 1 Same, 1 Different, and 3 Filler items had accuracies in which 25 to 37 % of subjects responded incorrectly to them. Eighteen target-sentence items had high failure rates (failed by greater than 25% of subjects). However, given the confound of experimental manipulations on target accuracy (e.g., nearly half of the sentences with high error rates were targets in the Different condition), these were not necessarily bad items. Rather, these varying rates suggested some true differences in difficultly between conditions, as intended.

When examining items for high failure rates on *both* the prime and target sentence, only one item met this criterion (failed by 35% and 31%, respectively), suggesting that children may not have been familiar enough with the particular word (pit). Given that over 60% of subjects responded correctly to one or both sentences, however, this item was retained in analyses. Overall, then, items were deemed, at least qualitatively, to have acceptable validity.

Inter-Condition Accuracy and RT Correlations

Inter-condition correlations for accuracy are reported in Table 35, while inter-condition correlations for reaction time are reported in Table 36 for the visual version of the task (N=83) and in Table 37 for the auditory version of the task (N=14). As can be seen in the tables, accuracy and reaction time among conditions was highly correlated.

Accuracy-Reaction Time Correlations

Correlations between RT and Accuracy were examined to ensure that accuracy effects did not result solely from patterns of impulsive responding or low effort. Significant correlations between RT and Accuracy were found for primes as well as targets in the Same ($r=-0.27$, $p=.02$ for primes and targets) and Nonsense conditions ($r=-0.39$ and $r=-0.38$, $p<.001$, primes and targets, respectively) but not in the Different condition ($r=-0.003$, $r=-0.12$ respectively). For prime to target change scores (i.e., the "adjusted" condition scores used to calculate cost and benefit), the correlation between accuracy and reaction time was significant for the Nonsense condition only ($r=-.338$, $p<.01$).

Since correlations between RT and Accuracy did not occur across *all* conditions, findings suggest that--at least across groups—the correlations in the Same and Nonsense conditions resulted from the increased difficulty of the stimuli (see above findings) rather than from inattentive or impulsive responding (These will be examined by groups below). This finding is important, as it provides a foundation for interpreting any group differences as stemming from "real" cognitive effects rather than simply from lack of effort, impulsivity, or carelessness (often possibilities when interpreting the performance of children with ADHD).

Comparison to findings in Gernsbacher, Robertson, and Werner (2002)

Current error rates were very similar to those found in Gernsbacher, Robertson, and Werner's (2001) sample of college students. In that sample, error rates to *target* sentences were as follows: 18% for the Same condition, 22% for the Nonsense condition, and 32% for the Different condition. It is interesting to note that the current sample actually performed somewhat better than Gernsbacher and colleagues' sample in the Same and Nonsense conditions but more poorly in the Different condition. The sentences used in the current study were intentionally simplified and shortened in comparison to the sentences used by Gernsbacher et al. to be more appropriate for a child population. Better performance in the current study is thus not entirely surprising and suggests that the cognitive process underlying task performance in these two conditions may be fully developed in school-age children.[62] The *higher* error rates compared to the Gernsbacher sample in the Different condition is therefore particularly striking and suggests a possible developmental effect related to inhibition.

[62] Reaction times were, not surprisingly, significantly slower than those of college students by—on average—approximately 1500 ms.

Table 35 Accuracy Correlations Among Ambiguous Words Task Conditions and Age for Both Primes and Targets.

	Prime-Different	Prime-Same	Prime-Nonsense	Prime-Filler	Target-Different	Target-Same	Target-Nonsense	Target-Filler
Age		.219+	.210+		.108	.165^	.269+	.149+
Prime –Different	.	.425**	.113	.374**	.365**	.496**	.432**	.224*
Prime –Same		.	.156		.316**	.494**		.194
Prime –Nonsense			.	.667**	-.073	.230*	.241*	.659**
Prime –Filler				.	.065	.357**	.362**	.793**
Target –Different					.	.431**	.423**	-.122
Target –Same						.	.450**	.240*
Target –Nonsense							.	.089
Target –Filler								.

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
+ Correlation is significant at the 0.05 level (1-tailed).
^ Correlation is marginally significant at the 0.05 level (1-tailed).

Table 36. Reaction Time Correlations Among Ambiguous Words Task Conditions for Primes and Targets (Visual Version: N=83).

	Prime - Different	Prime -Filler	Prime – Nonsense	Prime-Same	Target – Different	Filler	Target - Nonsense	Target - Same
Age	-.216*	-.247*	-.181	-.197	-.156	-.255*	-.222*	-.162
Prime-Different	.	.683**	.502**	.698**	.671**	.643**	.607**	.503**
Prime –Filler		.	.781**	.755**	.786**	.902**	.823**	.637**
Prime –Nonsense			.	.569**	.482**	.807**	.709**	.463**
Prime –Same				.	.787**	.710**	.728**	.769**
Target –Different					.	.725**	.709**	.707**
Target –Filler						.	.850**	.634**
Target –Nonsense								.672**
Target –Same								.

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed)

Table 37. Reaction Time Correlations Among Ambiguous Words Task Conditions for Primes and Targets (Auditory: N=14).

	Prime Different	Prime Filler	Prime Nonsense	Prime Same	Target Different	Target Filler	Target Nonsense	Target Same
	.	.171	-.017	-.027	.062	.161	.125	.001
Prime –Filler		.	.437	-.051	.132	.871**	.097	.132
Prime –Nonsense			.	.425	.617*	.611*	.253	.503
Prime-Same				.	.548*	.142	.661*	.721**
Target –Different					.	.206	.179	.748**
Target –Filler						.	.377	.360
Target –Nonsense							.	.620*
Target –Same								.

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Task Inconsistencies and Statistical Controls

Group Inconsistencies in Nonsense Condition Responses

Inconsistencies in group performance on the Nonsense condition are discussed in more detail in categorical analyses. However, for current purposes, it is relevant to note that inhibition hypotheses were often secondarily checked by exploring performance in the Different condition only (i.e., by exploring changes in performance from prime to target) independently of the Nonsense condition baseline. Findings for these alternate analyses are reported where relevant.

Problems with RT "Costs"

As can be seen from examination of RT means in Table 36, RT to targets following a different-meaning prime in the Different condition were not, on average, actually *slower* than prime RT. Thus, technically, RT was facilitated (or, at minimum, was equivalent to prime RT). When compared to prime-target RT changes in the other conditions, change in RT for the Different condition was still smaller than for the Same and Nonsense conditions. Thus, for the purposes of interpretation, RT changes in the Different condition can still likely be regarded as weak support for functioning of interference control or inhibitory mechanisms. However, they *cannot* be interpreted as representing full inhibition of non-selected homograph meanings. These RT findings will be important to account for when interpreting the overall pattern of results.

Prime Accuracy and Prime RT Inconsistencies Among Conditions

Contrary to expectations, paired samples t-tests examining prime accuracy and prime RT in each experimental condition (Same, Nonsense, Different) for the entire sample (*across groups and across task version*) revealed that accuracy for prime sentences among the experimental conditions was not equivalent. Primes in the Same condition had the lowest accuracy, followed by primes in the Nonsense condition, then primes in the Different condition. Thus, accuracy for primes in the Same condition was significantly worse than accuracy for prime sentences in the Different condition [$t(1,96)=3.34$, $p<.001$]. In addition, mean accuracy for prime sentences in the Nonsense condition (across groups and task versions) was intermediate between Same and Different prime accuracy and was marginally worse than accuracy in the Different condition [$t(1,96)=1.73$, $p<.09$]. This difference became statistically significant when the analysis was constrained to the performance of Control children [$t(1,33)=2.21$, $p<.04$].

Reaction time (constrained to the 83 subjects who received the visual version of the task; see Table 36) was also not equivalent across prime conditions and was significantly longer for primes in the Same and Nonsense conditions versus the Different condition [$t(1,82)=4.48$, $p<.001$; $t(1,82)=3.40$, $p=.001$, respectively]. These results did not hold for the auditory task-- likely because of the very large standard deviation in prime RT in the Different condition (see Table 37).

Condition variability in prime sentence responses likely resulted directly— although unintentionally-- from the experimental design. As noted above, the Different condition employed dominant-meaning prime sentences, whereas the Nonsense and Same conditions utilized no-meaning and subordinate-meaning primes, respectively. These experimental manipulations were intended to maximize potential inhibitory effects. However, proficiency with lower-frequency (i.e., subordinate) homonyms, as well as in interpretation of "nonsense" sentences, was clearly more difficult (although subtly so, as evidenced by mean error rates and accuracies in Tables 36 & 37) than interpretation of high-frequency primes.[63]

	Accuracy		Reaction Time	
	Corrected	Uncorrected	Corrected	Uncorrected
Auditory	0.29 (.21)	0.22 (0.17)	48.4 (1779.4)	427.13 (540.49)
Visual	0.23(.21)	0.21 (0.17)	713.8 (1419.1)	349.1 (880.0)

Age Effect Inconsistencies Among Conditions and Age-Corrections

Correlation analyses revealed modest age effects which were covaried in all analyses so that slight differences in age between groups would not account for effects. Correlations between age and accuracy on primes and targets varied from r=.11 to .27 (see Table 35). A regression analysis with age as a predictor also indicated that age significantly predicted accuracy for nonsense condition targets, marginally predicted accuracy for same targets, and did not significantly predict different condition targets. Correlations between reaction time and age on primes and targets varied from r=-.16 to -.26 (see Tables 36 & 37).

As a secondary check of analyses, age-corrected standardized residual scores were created for primes and targets in each of the conditions by regressing age on accuracy scores. Results remained unchanged in all analyses when utilizing this approach. Thus, only results for analyses in which age was covaried will be reported here.

[63] Whether this manipulation produced similar problems in Gernbacher et al.'s sample was not documented in their study. Thus, whether this was a developmental effect is unclear.

Preliminary Analyses of Inhibition Effects across Groups

Paired samples t-tests were utilized to determine whether the predicted experimental inhibition effects occurred in the task overall (ignoring groups). As seen in Table 35, across all groups (and with auditory and visual versions of the task combined), children incurred a significant **24%** accuracy **Cost** when comparing the adjusted accuracy in the Nonsense condition (mean: 0.02 ± 0.17) to the adjusted accuracy in the Different condition (mean: 0.26 ± 0.17) [$t(1,96)=-11.12$, $p<.001$]. With regard to RT findings, for the visual version of the task (across all groups), children incurred a significant **842 ms Cost** when comparing the change in reaction time from prime to target in the Nonsense (mean change in RT=-941 ms) versus Different (mean change in RT=-99ms) conditions [$t(1,82)=5.82$, $p<.001$].[64]

Dimensional Analyses: Additional Results for Visual Task

Note that the significant IQ-Reading Discrepancy/Accuracy Cost correlation likely was largely an artifact of the IQ correlation (partial correlation between Cost and Discrepancy with Full Scale IQ controlled: $r=-.13$, n.s). Regression analyses also revealed that Achievement-IQ Discrepancy (i.e., difference between achievement and aptitude) significantly predicted accuracy Cost. This finding was no longer significant after controlling for IQ, although IQ only accounted for approximately half of this effect (IQ-Discrepancy correlation: $r=.64$, $p<.001$).

[64] Children responded significantly faster to targets than to primes in the Nonsense condition [$t(1,82)=8.04$, $p<.001$], but not in the Different condition [$t(1,82)=0.94$] (despite the decrease in *mean* RT from prime to targets in the Different condition).

Table 38. Inattention Correlations with Accuracy and Reaction Time by Condition.

			Total Inattention Symptoms	ARS Teacher Inattention Raw	Teacher BASC Attention Problems	Teacher Conners ADHD Index
Prime	**Accuracy**	**Different**	-.262*	-.223+	-.120	-.128
		Same	-.308**	-.333**	-.399***	-.276*
			-.018	-.018	-.227*	-.097
		Filler		-.267*	-.369***	-.310**
	RT	**Different**	.073		.150	.105
		Same	.178	.189		.104
		Nonsense		-.008	.037	-.020
		Filler	.072	.079	.127	.036
Target	**Accuracy**	**Different**	-.386***	-.335**	-.374***	-.291*
		Same	-.357**	-.300**	-.360**	-.220+
		Nonsense	-.299**	-.232*	-.265*	-.162
		Filler	-.179	-.222+	-.267*	-.258*
		Different	.062	.065	.079	-.023
			.179	.153	.140	-.036
		Nonsense	.129	.160	.171	.065
		Filler	-.005	.056	.137	.063

*** p<0.001 (2-tailed); ** p< 0.01 (2-tailed); * p< 0.05 (2-tailed), + p<.06 (2-tailed)

Note that symptoms of hyperactivity did not significantly predict RT Cost (see Table 38), nor did mean reading achievement, or the interaction of reading achievement and inattention. The strongest prediction of RT Cost was obtained from teacher-rated learning problems, which remained significant after controlling for age and IQ. Importantly, when teacher-rated learning problems and inattention symptoms were used to predict RT Cost, learning problems were a much stronger predictor of performance. Thus, learning problems appeared to moderate the relationship between inattention and RT Cost.

Categorical Analyses for ADHD and Control Children on the Visual Task

There were significant 2-way interactions for Group*Condition [F(1,60)=4.06, p<.05], Group* Stimulus [F(1,60)=4.34, p<.05], and Condition*Stimulus [F

(1,60)=96.30, p<.001], but the 3-way Group*Condition*Stimulus interaction was not significant. In the Group*Condition Interaction, ADHD children had much poorer accuracy in the Different condition (averaged across primes and targets) versus Control children, but did not significantly differ in the Nonsense condition. Across all subjects, accuracy to targets in the Different condition was far worse than accuracy to primes, whereas accuracy to primes and targets in the Nonsense condition was similar. Finally, across conditions, performance of ADHD children was worse to targets than primes, whereas Control children did not have significant differences in accuracy for primes versus targets.

Explanation of Group Differences in Nonsense Condition Performance

Examination of the means for performance on primes and targets in the Nonsense condition revealed that ADHD-C and Control groups did not respond equivalently to the experimental manipulation in the Nonsense condition [$F(1,51)=3.38$, $p<.08$; see Figure 10], such that Control children's accuracy improved from prime-target (Prime-Target difference: 0.04 + .18), whereas ADHD children's accuracy decreased (Prime-Target difference: -0.06 + .17).. Given that the Nonsense condition was designed to act as the "baseline" from which to determine Cost to targets in the Different condition, findings of group differences violates assumptions necessary for using the Cost score to examine group differences in interference control and suggests that comparing prime-target changes in the Different condition may provide a more valid check of group differences in interference control.

Figure 9. Group by Stimulus Interaction for Control vs. ADHD-C in the Nonsense Condition.

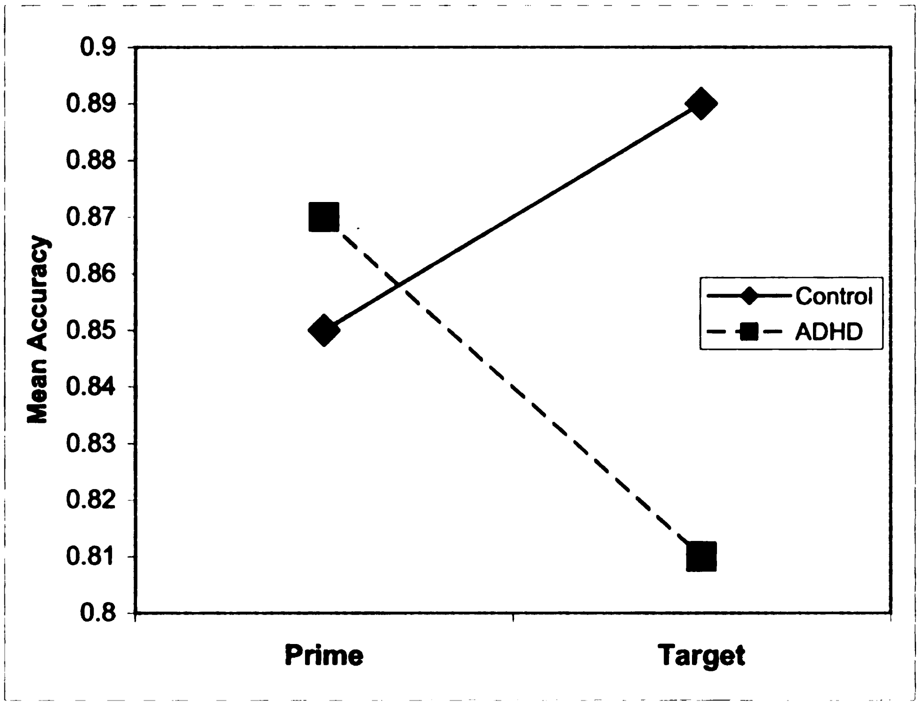
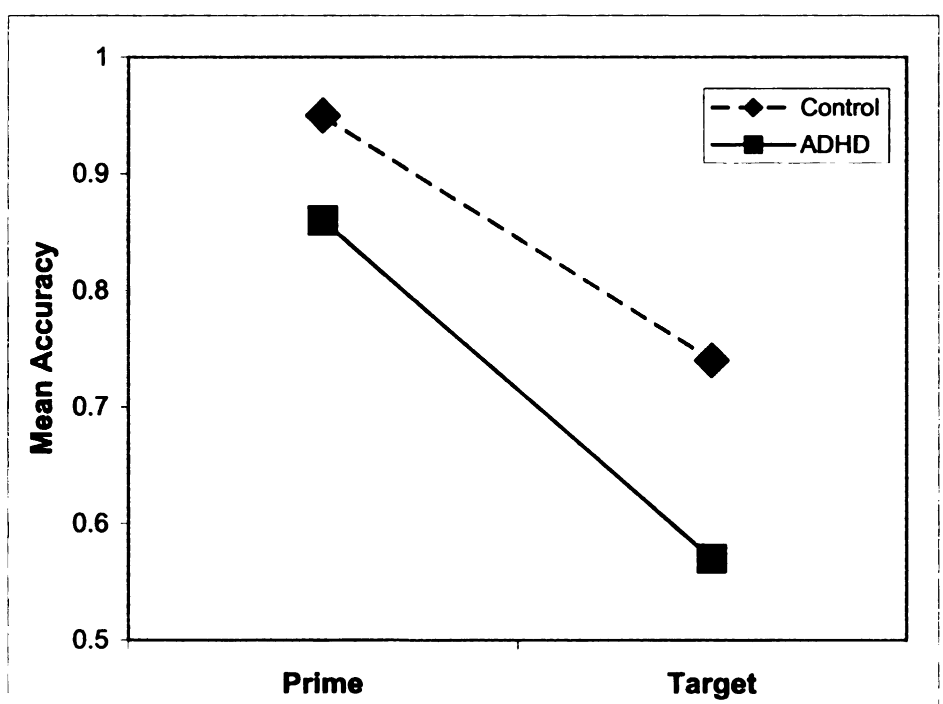


Figure 10. Group by Stimulus Interaction for Control vs. ADHD-C in the Different Condition.



Additional RD Findings on the Ambiguous Words Task

For RD children who took the auditory task, higher IQ was associated with a trend towards *increased* interference (RT Cost; non-significant trend). In addition, opposite to accuracy findings in these children, there was a positive associational trend between the measure of expressive language/working memory and RT Cost, such that weaker working memory was associated with *decreased* interference.

With regard to RT data, for RD children who received the visual version of the task, high levels of oppositional/aggressive behavior were significantly associated with reduced RT Costs (see Table 36). Note also that increased aggressive/oppositional behavior, although non-significant, was also associated with reduced RT Benefits.

Teacher ratings of inattention showed a nonsignificant trend towards predicting reduced accuracy Cost when IQ and age were controlled. Analyses revealed a strong positive effect of age (β=.48) which obscured the negative relationship between higher teacher-rated inattention and reduced accuracy Cost (β=-.50). Thus, increased teacher-rated symptoms of inattention in this group was associated with a *reduced* cost in accuracy when age effects were controlled (signaling a potential inhibitory deficit—i.e., both meanings of the word were more active).

With regard to RT, performance on the expressive language/working memory measure (Recalling Sentences) also did not strongly predict RT interference in isolation. However, when inattention, reading achievement, and Recalling Sentences scores were simultaneously used to predict RT Cost, there was a nonsignificant trend towards good prediction (R^2=.39), with inattention (β=-.43) and reading achievement (β=-.24) negatively predicting cost and Recalling Sentences positively predicting RT Cost (β=.47).

Thus, like findings for inattention, poorer performance on the expressive language/working memory measure was associated with reduced RT Cost.

In RD children receiving the visual task, there was a trend toward an interaction between reading achievement and inattention in predicting RT Cost; however, given the very small number of subjects this interaction is not interpretable.

Garden Path Task

Preliminary Data Checks

Item Analysis

Based upon analysis of control and filler item accuracies, all items had good reliability across subjects and were appropriate for inclusion in analyses. Individual items were examined to determine whether failure rates for any particular sentences were particularly high. Accuracies were examined separately for auditory and visual versions of the task. On the visual version of the task, on control sentences (i.e., non-garden path Reflexive Absolute Transitive [RAT] and Optional Transitive, subordinate-matrix sentences), all items were responded to with better than 65% accuracy across subjects. The mean accuracy across all control items was 89%, while mean accuracy on Filler sentences was 86%. Thus, these figures suggest that individual control items had good reliability across subjects and that all task items were appropriate for inclusion in analyses.

Inter-Condition Correlations

Accuracies on the various garden path conditions were, not surprisingly, highly inter-correlated (See Table 39).

Table 39. Inter-Condition Correlations Among Garden Path Task Conditions (Across Visual and Auditory: N=97).

	RAT-P	RAT-IP	OT-P	OT-IP	Control-RAT-P	control-RAT-IP	Control-OT-P	Control
Age	.177+	.143	.179+	.179+	.066	.029	.127	.150
Full Scale IQ	.385***	.286***	.478***	.358***	.184+	.249*	.388***	.086
RAT-P	.	.609***		.540***	.239*		.539***	.279**
RAT-IP		.	.540***	.665***	.433***	.351***	.424***	.284**
OT-P				.627***	.257*	.321***	.522***	.338***
OT-IP				.	.430***	.474***	.498***	.347***
Control-RAT-P							.242*	.228*
Control RAT-IP						.	.229*	.307**
Control-OT-P								.327***
Control-OT-IP								.

RAT: Reflexive Absolute Transitive; OT: Optional Transitive; P: Plausible; IP: Implausible; cont-P: Non-Garden Path Control: Plausible; cont-IP: Non-Garden Path Control Implausible
*** $p \leq .001$, ** $p < .01$, *$p < .05$ (2-tailed), + $p < .10$ (2-tailed)

Table 40. Inter-Condition Accuracy Correlations Among Garden Path Task Composites (across Visual and Auditory Task)

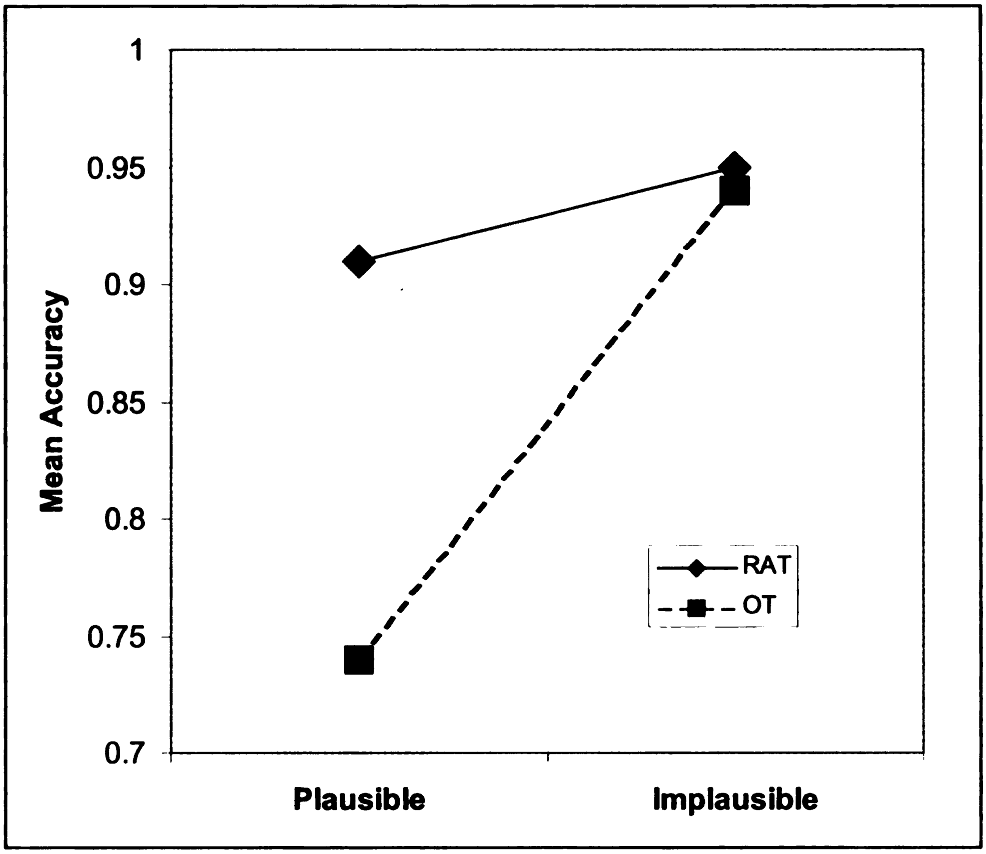
	OT: Garden Path Effect: Plausible	RAT: Garden Path Effect: Plausible	OT: Garden Path Effect: Implausible	RAT: Garden Path Effect: Implausible	OT: Plausibility Effect: GP	RAT: Plausibility Effect: GP	OT: Plausibility Effect: NonGP	RAT: Plausibility Effect: NonGP
Age	-.064	-.116	-.071	-.115	-.060	-.051	-.043	-.029
Full Scale IQ	-.123	-.225*	-.293**	-.081	-.274**	-.140	-.348***	.052
OT: Garden Path Effect: Plausible	.	.072		.059	.530***	-.046	-.464***	-.064
RAT: Garden Path Effect: Plausible		.	.127	.141	.288**	.594***	.278**	-.478***
OT: Garden Path Effect: Implausible			.	.244*	-.210*	-.102	.481***	.010
RAT: Garden Path Effect: Implausible					.090	-.338***	.215*	.553***
OT: Plausibility Effect: GP					.	.232*	.142	-.033
RAT: Plausibility Effect: GP						.	.165	-.131
OT: Plausibility Effect: NonGP							.	.046

Table 41. Accuracy Correlations Among Garden Path Task Conditions (Auditory Task Only: N=14).

	RAT-P	RAT-IP	OT-P	OT-IP	control-RAT-P	control-RAT-IP	control-OT-P	control OT-IP
RAT-P	.	.620*	.670**	.650*	.371	.362	.568*	.709**
RAT-IP	.620*	.	.378	.681**	.637*	.251	.443	.572*
	.670**	.378	.	.597*	.414	.306	.732**	.473+
OT-IP	.650*	.681**	.597*	.	.547*	.485+	.641*	.484+
Control-RAT-P	.371	.637*	.414	.547*	.	.122	.261	.194
Control RAT-IP	.362	.251	.306	.485+	.122	.	.118	.519+
Control-OT-P	.568*	.443	.732**	.641*	.261	.118	.	.514+
Control-OT-IP	.709**	.572*	.473+	.484+	.194	.519+	.514	.

RAT: Reflexive Absolute Transitive; OT: Optional Transitive; P: Plausible; IP: Implausible; control-P: Non-Garden Path Control: Plausible; control-IP: Non-Garden Path Control Implausible
** $p<.01$, *$p<.05$, +$p<.10$ (2-tailed)

Figure 11. Verb x Plausibility Interaction for Control Subjects on the Garden Path Task.



Effect of Plausibility on Garden Path Inhibition (across verb types; Table 42)

To evaluate whether the plausibility of the garden path influences revision or adjustment of the resulting misinterpretation, the effect of plausibility on garden pathing (i.e., whether garden path misinterpretations were plausible or implausible) was compared to plausibility effects on non-garden path control sentences (across verb types). This analysis revealed a different pattern of results than was obtained for global garden path effects. Mean achievement and expressive language/working memory (Recalling Sentences) performances were not predictive of garden path plausibility effects. In contrast, the strongest predictor of garden path plausibility effects was performance on the measure of receptive language (Concepts and Directions). Whereas higher IQ was related to stronger inhibition effects (larger differences between plausible and implausible garden path effects), poorer receptive language ability (Concepts and Directions) was associated with smaller differences in plausible versus implausible garden path effects, indicating a failure to utilize implausibility (and therefore effortful inhibition) to direct revision of garden path misinterpretations.[65] Teacher-rated learning problems and total hyperactivity symptoms were similarly predictive of plausibility effects (i.e., inhibition failures manifested by sustained garden path effects in the implausible condition).[66]

Table 42. Plausibility Effect on Garden Pathing (across verb type).

	Variable	R^2	Adj. R^2	ΔR^2	F for $R^2\Delta$	$\beta^{\dagger}$	T
1	**Mean Achievement**	.01	-.00	.01	0.70 (1,95)	.09	0.84
1	**Total Inattention Symptoms**	.02	.01	.02	1.59 (1,95)	-.13	-1.26
1							
Step 1	**Age**	.00	-.02	.00	0.09 (1,94)	-.11	-0.95
	Full Scale IQ					-.01	-0.08
Step 2	**Mean Achievement**	.03	-.01	.03	1.38 (2,92)	.10	0.80
	Total Inattention Symptoms					-.14	-1.27
Step 3	**Interaction (Achiev.*Inatt.)**	.04	-.02	.00	0.41 (1,91)	.07	0.64
1	**Total Hyperactive Symptoms**	.03	.02	.03	3.25 (1,95)$^{+}$	-.18	-1.80^{+}
2							
Step 1	**Age (months)**	.04	.01	.04	3.65 (1,93)$^{+}$	-.04	-0.41
Step 2	**Full Scale IQ (estimated)**					-.08	-0.74
Step 3	**Total Hyperactive Symptoms**					-.20	-1.91^{+}
1	**Learning Problems (Teacher)**	.03	.02	.03	2.91 (1,95)$^{+}$	-.17	-1.71^{+}
2	**Age (months)**	.04	.01	.04	4.10 (1,93)*	-.04	-0.34
	Full Scale IQ					-.13	-1.17
	Learning Problems (Teacher)					-.22	-2.03*

[65] The logic for this is as follows: This comparison takes Plausible GP Effect-Implausible GP Effect. Smaller index scores (differences) indicate large garden path effects for <u>both</u> plausible *and* implausible conditions (or small GP effects for plausible and implausible conditions—unlikely given overall task effects and condition means), whereas larger differences on this index score indicate a large GP effect in plausible condition and small GP effect in implausible condition (this would be the expected "inhibitory pattern")

[66] Note that the direction of this effect is in the opposite direction to receptive language findings because *greater* problems on this measure are associated with *higher* scores.

Model	Variable	R^2	Adj. R^2	Δ R^2	F R^2Δ	β†	T
1	**Recalling Sentences**	.01	-.00	.01	0.66 (1,95)	.08	0.81
1	**Passage Comprehension**	..01	-.00	.01	0.94 (1,95)	.10	0.97
1	**Concepts and Directions**	.09	.08	.09	9.37 (1,95)**	.30	3.06**
2	**Age**	.14	.11	.13	14.29 (1,93)†	.04	0.43
	Full Scale IQ					-.23	-2.12*
	Concepts and Directions					.42	3.78†
3							
Step 1	**Age**	.00	-.02	.00	0.09 (2,94)	.05	0.50
	Full Scale IQ					-.25	-2.12*
Step 2	**Mean Achievement**	.02	-.02	.01	1.20 (1,93)	.04	0.33
Step 3	**Concepts and Directions**	.14	.10	.12	12.90 (1,92)†	.41	3.59†

†p<.001, **p<.01, *p<.05; NonGP-GP for P vs. IP

Effect of Verb Type on Garden Pathing (across Plausibility Types, Table 43)[67]

To determine whether inhibitory effects are influenced by verb type (specifically, whether RAT verbs—like implausible sentences—can deploy inhibitory mechanisms to reduce garden path effects), garden path effects were examined for RAT versus OT verbs (across plausibility). As shown in Table 43, neither hyperactivity, inattention, reading achievement, nor the interaction between inattention and reading achievement significantly predicted the effect of verb type on garden-pathing (across plausibility conditions), nor did reading comprehension or receptive language (Concepts and Directions) abilities. Thus, at least when plausibility effects were not taken into account, problems with inattention or reading achievement did not interfere with the typical and expected reduction in garden path effects from RAT verbs. Such a finding would go *against* the idea of a *global* inhibitory deficit in syntactic revision/re-analysis of garden path misinterpretations and instead leaves open the possibility that inhibitory effects

[67] NonGP-GP for RAT vs. OT.

occur at the level of semantic/inferential interpretations (i.e., re-analysis occurs when implausible inferences drive inhibition or revision of the garden path misinterpretation).

Table 43. Effect of Verb Type on Garden Pathing (across Plausibility Types)—NonGP-GP for OT vs. RAT

	Variable	R^2	Adj. R^2	ΔR^2	F For $R^2 \Delta$	$\beta^{\dagger}$	T
1	**Mean Achievement**	.01	-.00	.01	0.75 (1,95)	-.09	-0.87
1	**Total Inattention Symptoms**	.00	-.01	.00	0.38 (1,95)	-.06	-0.62
1	**Teacher Inattention (BASC)**	.00	-.01	.00	0.00 (1,95)	-.00	-0.02
1							
Step 1	**Age**	.01	-.02	.01	0.23 (2,94)	.03	0.26
	Full Scale IQ					.03	0.29
Step 2	**Mean Achievement**	.02	-.03	.01	0.53 (2,92)	-.10	-0.84
	Total Inattention Sympts.					-.07	-0.65
Step 3	**Interaction (Achiev.*Inatt.)**	.02	-.04	.00	0.05 (1,91)	-.02	-0.22
1	**Total Hyperactive Symptoms**	.00	-.01	.00	0.12 (1,95)	-.04	-0.35
1	**Learning Problems (Teacher)**	.00	-.01	.00	0.13 (1,95)	.04	0.36
1	**Recalling Sentences**	**.04**	**.03**	**.04**	**4.12 (1,95)***	**.20**	**2.03***
2	**Age (months)**	**.08**	**.05**	**.07**	**7.11(1,93)****	**.12**	**1.13**
	Full Scale IQ					**-.17**	**-1.42**
	Recalling Sentences					**.33**	**2.67****
3							
Step 1	**Age**	**.01**	**-.02**	**.01**	**0.23 (2,94)**	**.08**	**0.74**
	Full Scale IQ					**-.12**	**-1.01**
Step 2	**Mean Achievement**	**.01**	**-.02**	**.01**	**0.62 (1,93)**	**-.20**	**-1.68†**
Step 3	**Recalling Sentences**	**.10**	**.06**	**.09**	**9.41 (1,92)****	**.39**	**3.07****
1	**Passage Comprehension**	.01	-.00	.01	0.90 (1,95)	-.10	-0.95
1	**Concepts and Directions**	.00	-.01	.00	0.02 (1,95)	.01	0.13

$^{\dagger}p<.001$, $^{**}p<.01$, $^{*}p<.05$

In contrast, to these findings, the measure of expressive language/working memory (Recalling Sentences) *did* predict verb type effects on garden pathing, such that poorer performance was associated with smaller differences *between* RAT and OT garden path effects (i.e., RAT verbs did not provide the expected reduction in garden path effects). Thus, expressive language/working memory ability was predictive of large garden path effects in *both* RAT and OT verb conditions, indicating the possibility of more global inhibitory deficits at the level of syntactic re-analysis for those with expressive language/working memory problems (at least when plausibility effects are not considered).

Effect of Verb and Plausibility on Garden Pathing.

In order to examine further whether inhibitory deficits were localized to the semantic inference versus syntactic re-analysis levels, additional regression analyses simultaneously considered the effects of verb type and plausibility on garden path effects. Inattention was weakly negatively predictive of verb by plausibility differences on garden pathing across a number of indices of inattention. Thus, effects were consistent for RAT and OT verbs, and signified that inhibition failures (specifically, failure for implausible sentences to drive inhibition of semantic misinterpretation) were weakly globally present for both RAT and OT verbs[68]. This finding offers weak support for a syntactic locus of inhibitory deficits that could operate <u>in addition to</u> a semantic inferencing inhibitory effect. Results do, however, provide the strongest support for an inhibitory effect that is primarily inference-driven.

Reading achievement did not predict this composite score. However, as in findings reported above for verb effects on garden-pathing, performance on the measure of expressive language/working memory (Recalling Sentences) did weakly predict the current composite score, such that global garden path effects for both RAT and OT verbs were consistent in both the plausible *and* implausible conditions (again indicating reduced effectiveness of implausibility-driven activation of inhibitory mechanisms).

[68] Note that this interpretation is based upon additional knowledge gleaned from earlier findings of garden path plausibility effects. In the absence of that prior information, it would also be possible for this result to be interpreted as representing consistency of *inhibitory* effects (rather than deficits) across both verb types. See Table XXX (p.XXX) of ADHD group effects on individual conditions for further illustration of the current interpretation of this effect.

Thus, inference-driven inhibition deficits, caused garden path effects in both RAT and OT verbs to be maintained. Thus, these findings suggest that expressive language/working memory difficulties are associated with both syntactic and semantic level inhibition deficits. Note that none of these results were robust to IQ and age controls.

Table 44. Comparison of Plausibility and Verb Type on Garden Path Effect (Verb*Plausibility*GP Interaction)

	Variable	R^2	Adj. R^2	ΔR^2	F for $R^2\Delta$	$\beta^{\dagger}$	T
1	**Mean Achievement**	.01	-.01	.01	0.46 (1,95)	.07	0.68
1	**Total Inattention Symptoms**	**.04**	**.03**	**.04**	**3.41 (1,95)$^{+}$**	**-.19**	**-1.85^{+}**
2							
Step 1	**Age (months)**	**.00**	**-.01**	**.00**	**0.00 (1,95)**	**.01**	**0.07**
Step 2	**Full Scale IQ (estimated)**	**.03**	**.01**	**.03**	**2.52 (1,94)**	**.13**	**1.21**
Step 3	**Total Inattention Symptoms**	**.05**	**.02**	**.02**	**2.32 (1,93)**	**-.16**	**-1.52**
1	**Teacher Inattention (BASC)**	**.04**	**.03**	**.04**	**4.40 (1,95)***	**-.21**	**-2.10***
2							
Step 1	**Age (months)**					**.01**	**0.08**
Step 2	**Full Scale IQ**					**.10**	**0.94**
Step 3	**Teacher Inattention Sympts.**	**.05**	**.02**	**.03**	**2.68 (1,93)**	**-.18**	**-1.64**
1							
Step 1	**Age**	.03	.01	.03	1.26 (2,94)	.00	0.01
	Full Scale IQ					.13	1.16
Step 2	**Mean Achievement**	.05	.01	.02	1.16 (2,92)	-.02	-0.15
	Total Inattention Symps.					-.16	-1.51
Step 3	**Interaction (Achiev.*Inatt.)**	.05	-.00	.00	0.00 (1,91)	-.01	-0.06
1	**Total Hyperactive Symptoms**	.00	-.01	.00	0.04 (1,95)	-.02	-0.19
1	**Learning Problems (Teacher)**	.01	.00	.01	1.00 (1,95)	-.10	-1.00
1	**Recalling Sentences**	**.05**	**.04**	**.05**	**4.63 (1,95)***	**.22**	**2.15***
2	**Age (months)**	**.05**	**.02**	**.03**	**2.51 (1,93)**	**.06**	**0.56**
	Full Scale IQ					**.06**	**0.46**
	Recalling Sentences					**.20**	**1.58**
3							
Step 1	**Total Inattention Symptoms**	**.04**	**.03**	**.04**	**3.41 (1,95)$^{+}$**	**-.16**	**-1.59**
Step 2	**Recalling Sentences**	**.07**	**.05**	**.04**	**3.72 (1,94)$^{+}$**	**.19**	**1.93^{+}**
1	**Passage Comprehension**	.00	-.01	.00	0.01 (1,95)	.01	0.11
1	**Concepts and Directions**	.01	-.00	.01	0.73 (1,95)	.09	0.86

$^{\dagger}p<.001$, $^{**}p<.01$, $^{*}p<.05$; [(contp-plaus)-(contip-implaus)] -[(conratp-ratp)-(conratip-rati)]./ GPVerbPlxEff=GPPlausOT-GPPlausRAT

APPENDIX B

Preliminary Analyses of Facilitation Effects across Groups

Facilitation (i.e., Benefit) Effects across Groups

Across groups, a significant **5% Benefit** in accuracy from prime to target occurred for the Same condition (mean: 0.03 $\pm$ 0.13) compared to the Nonsense condition [t(1,96)=2.19, p=.03]. This accuracy benefit was exactly equivalent to the 5% benefit incurred by Gernsbacher, Robertson, and Werner's (2001) college sample. Note that children who took the auditory version of the task incurred a non-significantly higher Benefit (mean: 0.10 $\pm$ 0.30) than those that received the visual version of the task [mean: 0.05 $\pm$ 0.22; F(1,95)=0.69].

Table 45. Auditory vs. Visual for Gernsbacher Task

	Auditory Version N=14	**Visual Version N=83**
Accuracy-Benefit	0.06 (0.12)	0.03 (0.15)
Corrected Accuracy-Benefit	0.10 (0.30)	0.04 (0.21)
RT-Benefit	-263.53 (404.35)	-32.3 (929.2)
Corrected RT-Benefit	103.9 (655.2)	84.9 (1188.3)

With regard to RT, contrary to predictions, there was no significant facilitation in reaction time when comparing change in response time from prime to target in the Nonsense *versus* the Same (mean change in RT=-860 ms) conditions for the visual task [t(1,82)=-0.59] or the auditory task [mean change in RT=+104 ms, t(1,13)=-0.59]. In contrast, Gernsbacher and colleagues' participants did demonstrate a RT Benefit (176 ms). It is important to note, however, that when children were compared in the Same condition *only* they did show significant facilitation from prime to target [Visual: 860 ms, $t(1,82)=9.39$, $p<.001$; Auditory: 265 ms, $t(1,13)=2.09$, $p<.03$, 1-tailed] and likewise on the Nonsense condition only [Visual: 941 ms, $t(1,13)=8.04$, $p<.001$; Auditory: 369 ms, $t(1,13)=3.50$, $p<.01$, 1-tailed]. The task thus clearly produced priming and facilitation effects, but these facilitation effects did not significantly differ for RT findings in the Same versus the Nonsense condition (although such differences did occur for accuracy comparisons as described above).

To summarize these preliminary facilitation effects: Findings supported the effectiveness of experimental manipulations as well as the effectiveness of accuracy and RT corrections and revealed Benefit (i.e., facilitation) effects for the visual as well as auditory versions of the Ambiguous Words Task. Accuracy data produced the clearest findings.

Facilitation Effects I: Visual Task Findings in Non-RD (ADHD/Control) Children

Dimensional Hypotheses: Correlations

IQ, Reading Achievement, and Language (Table 46). Full Scale IQ was not significantly correlated with accuracy or RT Benefit. Correlations between measures of reading achievement and accuracy/RT Benefit were all non-significant. However, teacher-rated learning problems did significantly correlate with accuracy and RT Benefit.

Table 46. IQ, Achievement, and Language Correlations for **Accuracy** and **RT** Benefit across Non-RD Groups on the Visual Task (N=75).

	Accuracy	**Reaction Time**
	Benefit	**Benefit**
Age	-.084	.152
Full Scale IQ (Estimated)	.086	.072
Nonverbal IQ (Estimated)	.201+	.009
Mean Reading Score	.010	.093
Passage Comprehension (SS)	.011	.120
Concepts and Directions (ss)	.054	.088
Recalling Sentences (ss)	.105	.049
BASC Learning Problems (Teacher-rated T-Score)	**.227***	**-.361****

*p<.05 (2-tailed); ** p<.02 (2-tailed); + p<.10 (2-tailed)

Inattention and Hyperactivity (Table 47). Inattention and hyperactivity were not significantly correlated with accuracy Benefit. However, inattention showed a marginally significant negative correlational trend with RT benefit, such that higher levels of inattention were associated with *reduced* facilitation effects in RT. Teacher-rated hyperactivity symptoms were also marginally significantly associated with reduced RT facilitation.

Table 47. Inattention and Hyperactivity Correlations for Accuracy and RT Benefit across Non-RD Groups (N=75)

	Accuracy Benefit	**Reaction Time Benefit**
Total Inattentive Symptoms	.146	**-.193+**
Total Hyperactivity Symptoms	.095	-.120
Mother-Ratings		
ARS Total Raw-Mother	.105	-.092
ARS Inattentive Raw	.103	-.106
ARS Hyperactivity Raw	.094	-.066
Teacher-Ratings		
ARS Total Raw	.155	**-.226+**
ARS Inattentive Raw	.052	**-.220+**
ARS Hyperactivity Raw	.110	**-.208+**
BASC Attention	.057	**-.231***

* p<.05 (2-tailed); + p<.08 (2-tailed)

Dimensional Hypotheses: Regressions

In regression analyses, reading achievement, total inattention symptoms, and total hyperactivity symptoms did not predict accuracy Benefit, and these results were unchanged when controlling for IQ and age. The interaction of inattention and reading achievement also did not significantly predict accuracy Benefit. Using correlations from the prior set of analyses as a guide, a limited number of additional regressions were performed to examine specific correlational findings. Using this method, teacher-rated learning problems were found to significantly positively predict accuracy Benefit over and above IQ and age effects (β=.32, t=2.53, p<.02).

Findings for RT facilitation mirrored those for inhibition-RT data on the visual task in Non-RD children. Thus, inattention (both total symptoms and teacher-rated) was predictive of a *reduced* Benefit in RT and ranged from significant to marginally significant, depending on the index of inattention that was used. Teacher hyperactivity ratings also marginally predicted reduced RT benefit. Subsequent analyses revealed that ratings of neither hyperactivity nor inattention had very much predictive power over and above one another ($r^2 \Delta$=.00), although inattention produced a stronger effect on RT Benefit (β=-.15) than did hyperactivity (β=-.09). These ratings thus likely tapped the same construct (Inattention-Hyperactivity correlation: r=.79, p<.001).

Table 48. RT Benefit Regressions for Visual Ambiguous Words Task (N=75)

Model	Variable	R^2	Adj. R^2	ΔR^2	F $R^2\Delta$	$\beta^{‡}$	t
1	Mean Achievement	.01	-.01	.01	0.63 (1,73)	.09	0.80
1	**Total Inattention Symptoms**	**.04**	**.02**	**.04**	**2.83 (1,73)$^{+}$**	**-.19**	**-1.68^{+}**
2	Full Scale IQ (estimated)	.01	-.01	.01	0.39 (1,73)	.08	0.71
	Age (months)	.04	.01	.03	2.22 (1,72)	.15	1.24
	Total Inattention Symptoms	.06	.02	.03	1.87 (1,71)	-.16	-1.37
1	**Teacher Inattention (BASC)**	**.05**	**.04**	**.05**	**4.13 (1,73)***	**-.23**	**-2.03***
2	Full Scale IQ	.07	.03	.03	2.55 (1,71)	.02	0.15
	Age (months)					.13	1.05
	Teacher Inattention (BASC)					-.21	-1.60
1							
Step 1	Mean Achievement	.04	.00	.04	1.08 (3,71)	.09	0.64
	Total Inattention Symptoms					-.20	-1.70+
	Full Scale IQ (estimated)					.01	-0.04
Step 2	Interaction (Achiev.*Inatt.)	.06	.01	.02	1.53 (1,70)	-.14	-1.24
1	**Teacher Hyperactivity (TARS)**	**.04**	**.03**	**.04**	**3.29 (1,73)$^{+}$**	**-.21**	**-1.82^{+}**
2	Age (mths)	.07	.03	.03	2.36 (1,71)	.15	1.26
	Full Scale IQ (estimated)					.08	0.67
	Teacher Hyperactivity (TARS)					-.18	-1.54
3	Teacher Hyperactivity (TARS)	.05	.03	.01	0.62 (1,72)	-.09	-0.48
	Teacher Inattention (TARS)					-.15	-0.79
4	Teacher Inattention (TARS)	.05	.03	.00	0.23 (1,72)	-.15	-0.79
	Teacher Hyperactivity (TARS)					-.09	-0.48
1	**Learning Problems (Teacher)**	**.13**	**.12**	**.13**	**10.91(1,73)†**	**-.36**	**-3.30†**
2	**Full Scale IQ**	**.15**	**.12**	**.12**	**10.02 (1,73)****	**-.06**	**-0.51**
	Age (months)					**.13**	**1.17**
	Learning Problems (Teacher)					**-.39**	**-3.17****
3	**Inattention (TARS)**	**.13**	**.11**	**.08**	**6.84 (1,72)***	**-.04**	**-0.28**
	Learning Problems					**-.34**	**-2.62***

$^{‡}\beta$ after final step; †$p \leq .001$; **$p \leq .01$; *$p \leq .05$; + $p \leq .10$

In contrast to accuracy findings for this group, teacher-rated learning problems significantly predicted a *reduced* RT Benefit that continued to be significant after controlling for age, IQ, and inattention. Note that inattention did not predict RT Benefit over and above that predicted by learning problems [r^2 Δ=.00; F(1,72)=0.08]. Despite the findings for teacher-rated learning problems, actual reading achievement (as measured experimentally) did not significantly predict RT Benefit (even after controlling for IQ and age), nor did the interaction between inattention and reading achievement.

Categorical/Group Hypotheses: ANOVA's

Accuracy. A 2 x 2 x 2 repeated measures analysis of variance with Condition (Nonsense versus Same) and Stimuli (Prime vs. Target) as the within subjects factors and Group (Control vs. ADHD-C) as the between subjects factor was used to examine Accuracy Benefit (i.e., facilitation). The 3-way interaction was not significant. However, there was a significant Group & Condition interaction [$F(1,51)=6.64$, $p=.01$], such that averaged across prime-target stimuli, ADHD children showed no accuracy differences in the Nonsense compared to the Same condition, whereas Control children improved their accuracy in the Nonsense compared to the Same condition.

Due to the earlier finding concerning group differences in performance in the Nonsense condition (see group comparisons of inhibitory effects in prior section; a 2 (Prime vs. Target) x 2 (Control vs. ADHD-C) repeated measures ANOVA also explored differences in accuracy Benefit (i.e., facilitation) in the Same condition. While this analysis revealed a main effect of ADHD [$F(1,51)=14.53$, $p<.001$], the Group*Stimulus interaction was not significant. Thus, there was no support for differences in facilitation for accuracy between ADHD and Control children.

Table 49. Mean Benefit (Facilitation) Scores by Diagnostic Group

	Control	ADHD-Only	
		Combined	Inattentive
Benefit (Corrected)			
(Nonsense - Same)			
Accuracy	0.01 (0.17)	0.06 (0.27)	0.07 (0.21)
Reaction Time	261.44 (982.4)	-252.0 (1231.2)	-53.4 (707.8)

Reaction Time. The 2 (Group) x 2 (Condition) x 2 (Stimulus) repeated measures ANOVA revealed a significant Stimulus main effect [$F(1,51)=58.06$, $p<.001$] and significant Stimulus * Condition interaction [$F(1,51)=24.72$, $p<.001$] but no significant interactions involving Group and no significant 3-way interaction. The follow-up 2 (Group) x 2 (Stimulus) repeated measures ANOVA for the Same condition also revealed no significant Group main effect nor significant interaction, although the Stimulus main effect was significant [$F(1,51)=94.55$, $p<.001$]. Thus, RT data also supported no group differences in facilitation.

Facilitation Effects II: RD Findings on the Auditory and Visual Tasks

Dimensional Hypotheses: RD Correlations for Auditory vs. Visual Task

IQ, Achievement, and Language (Table 50). As shown in Table 50, for RD children administered the auditory task (due to low reading ability), lower reading comprehension ability was associated with less facilitation/Benefit in accuracy. Weaker expressive language/working memory was also associated with decreased facilitation effects. (Or, alternatively, better reading comprehension and expressive language/working memory were associated with accuracy facilitation in the Same compared to the Nonsense conditions). In contrast, no strong trends or significant results existed for indices of achievement or language and RT facilitation.

RD children who took the visual task (N=8) showed no relationship between indices of IQ, reading, and language and accuracy Benefit. However, the correlation between mean reading achievement (average of word recognition, spelling, and phonological decoding) and RT Benefit was marginally significant ($r=.64$), such that higher reading scores in these RD children were associated with increased facilitation/benefit in RT. Likewise, these children showed an associational trend between younger age and increased RT facilitation.

Table 50. IQ, Achievement, and Language Correlations for Accuracy and RT Benefit for RD children

	VISUAL (N=8)		AUDITORY (N=12)	
	Accuracy	**Reaction Time**	**Accuracy**	**Reaction Time**
Age	.097	**-.632+**	-.300	.162
Full Scale IQ (Estimated)	-.202	.447	.070	-.226
Nonverbal IQ (Estimated)	-.475	.200	-.046	-.345
Mean Reading Score	-.306	**.678+**	.467	-.113
Passage Comprehension (SS)	-.244	.347	**.608***	.196
WIAT Reading (SS)	-.362	.573	.457	.099
Concepts and Directions (ss)	.325	-.141	.096	-.134
Recalling Sentences (ss)	-.331	-.091	**.684****	-.042
BASC Learning (T-Score)	.524	-.318	.354	.357

** p<.02 (2-tailed); * p<.05 (2-tailed); + p<.10 (2-tailed)

Inattention and Hyperactivity. Correlations between Benefit scores and symptoms of parent and teacher-rated inattention and hyperactivity for children with RD who received the visual versus auditory version of the task are shown in Table 51. For RD subjects who were administered the visual version of the task, there were no significant correlations for any indices of inattention or hyperactivity and facilitation (either accuracy or RT), although the correlation between teacher-rated hyperactivity on the BASC and accuracy Benefit was marginally significant ($\underline{r}$= .70).

For those RD children who received the auditory version of the task, there were also no significant correlations between accuracy Benefit and ratings of inattention or hyperactivity. Note, however, that opposite to the pattern in RD children administered the visual task, these RD children showed a consistent negative correlational trend between higher ratings of inattention and hyperactivity and reduced accuracy Benefit.

However, high levels of hyperactivity were associated with reduced RT facilitation on multiple mother and teacher indices (statistically significant or marginally significant on a number of indices).

Table 51. Inattention and Hyperactivity Correlations for Accuracy and RT Benefit for RD children on the Visual and Auditory Task

	VISUAL (N=8)		AUDITORY (N=12)	
	Accuracy	**Reaction Time**	**Accuracy**	**Reaction Time**
Total Inattentive Symptoms	.332	.253	-.297	.187
Total Hyperactivity Symptoms	.260	.135	-.139	**-.517+**
Mother				
ARS Total (Raw)	.241	.135	-.370	**-.571+**
ARS Inattentive (Raw)	.230	.154	-.404	-.470
ARS Hyperactivity (Raw)	.234	.085	-.313	**-.620***
BASC Attention (T-Score)	.143	.184	-.289	-.102
Teacher				
ARS Total (Raw)	-.037	.334	-.229	-.005
ARS Inattentive (Raw)	.208	.323	-.053	.137
ARS Hyperactivity (Raw)	-.361	.302	-.333	-.134
BASC Attention (T-Score)	.160	.482	.042	.257

*p<.05 (2-tailed); + p<.08 (2-tailed)

Conclusions. Overall, there was no association between facilitation effects and measures of inattention, although there was some support for a relationship between decreased facilitation and increased hyperactivity for RD children receiving the auditory task.

Dimensional Hypotheses: RD Regressions for Auditory vs. Visual Task

Auditory Task. There was a nonsignificant trend for reading achievement to predict accuracy Benefit for RD children who received the auditory version of the task ($R^2 = .22$, $R^2\Delta = .17$ after controlling age and iq), such that higher reading achievement was associated with increased benefit in this group ($\beta = .54$ after controlling IQ and age). Inattention symptoms did not significantly predict accuracy benefit by mother or teacher report, although controlling for inattention did improve the predictive power of reading achievement (since the two were in opposite directions; ($\beta_{reading}$= .56 vs. $\beta_{inattention}$ = -.17; R^2=.30 with iq and inattention controlled).

Mirroring findings on the auditory task for accuracy Cost, performance on the expressive language/working memory measure (Recalling Sentences) positively predicted accuracy Benefit, such that higher performance on this measure resulted in greater accuracy Benefit (Table 52). This effect remained after controlling for reading achievement, age, and inattention and became extremely strong after controlling for IQ.

Also inversely related to findings for accuracy Cost, passage comprehension performance in RD children receiving the auditory version of the task significantly positively predicted accuracy Benefit, with higher reading comprehension associated with increased accuracy Benefit (i.e., facilitation from prime to target; Table 52). This finding was not entirely (or even predominantly) accounted for by reading achievement. Accuracy facilitation effects also showed a trend towards predicting passage comprehension ability above and beyond total reading achievement ($R^2\Delta$ =.18; ($\beta_{reading}$= .29 vs. $\beta_{Benefit}$ = .47). Thus, in low functioning children with RD, facilitation may be associated with improved reading comprehension.

In contrast to the findings for facilitation effects in accuracy, for RT, neither reading achievement, inattention, nor the interaction of reading achievement and inattention showed a trend towards predicting RT facilitation (i.e., Benefit) after age and IQ were controlled. Passage comprehension and expressive language/working memory (i.e., Recalling Sentences) performance was also not predictive of RT facilitation (i.e., Benefit).

Table 52. RD Accuracy Benefit Regressions for Auditory Ambiguous Words Task (N=12)

Model	Variable	R^2	Adj. R^2	ΔR^2	F $R^2\Delta$	β‡	t
1	**Recalling Sentences**	.47	.42	.47	8.82 (1,10)	.68	2.97*
2	**Full Scale IQ**	.82	.75	.72	31.81 (1,8)†	-.83	-3.88**
	Age (months)					-.27	-1.64
	Recalling Sentences					1.2	5.64†
3	**Mean Achievement**	.51	.40	.29	5.28 (1,9)*	.22	0.83
	Recalling Sentences					.59	2.30*
4	**Mean Achievement**	.53	.35	.27	4.66 (1,8)+	.19	0.68
	Inattention					-.15	-0.62
	Recalling Sentences					.58	2.16+
1	**Passage Comprehension**	.37	.31	.37	5.88 (1,10)*	.61	2.43*
2	**Full Scale IQ**	.37	.14	.28	3.57 (1,8)+	-.06	-0.18
	Age					.01	0.02
	Passage Comprehension					.62	1.89+
3	**Mean Achievement**	.40	.27	.19	2.80 (1,9)	.21	0.71
	Passage Comprehension					.50	1.67
4	**DV=Passage Comprehension**						
Step 1	**Mean Achievement**	.26	.19	.26	3.49 (1,10)	.51	1.87+
Step 2	**Mean Achievement**	.44	.31	.18	2.80 (1,9)	.29	1.01
	Accuracy Benefit					.47	1.67

‡β after final step †$p \leq .001$; **$p \leq .01$; *$p \leq .05$; + $p \leq .10$

Visual Task. For RD children who received the visual version of the task, accuracy Benefit showed no trend for prediction by reading achievement, inattention, or an interaction between reading and inattention on accuracy Benefit. The primary finding was a non-significant trend for teacher-rated learning problems to positively predict accuracy Benefit (R^2=.28) even after controlling for IQ and age, such that increased learning problems were also associated with increased facilitation in accuracy (which was opposite to associations between reading and accuracy Benefit in RD children on the auditory task).

With regard to RT data, reading achievement significantly predicted RT Benefit after controlling for age and IQ, with higher reading achievement associated with increased facilitation in RT in these high functioning RD children (see Table 51). There was also a non-significant trend for inattention to predict RT Benefit (i.e., facilitation) after age and IQ were controlled, so that higher inattention was associated with increased RT facilitation. Together, reading achievement and inattention significantly predicted 70% of the variance in RT facilitation [$F(1,5)=5.80$, $p=.05$] for these RD children, with reading achievement producing the strongest effect (but inattention also serving as a marginally significant predictor in the model). There was no predictive interaction between reading achievement and inattention.

Table 53. RD Benefit RT Regressions for Visual Ambiguous Words Task (N=8)

Model	Variable	R^2	Adj. R^2	ΔR^2	F $R^2\Delta$	β‡	t
1	**Mean Achievement**	.46	.37	**.46**	5.11 (1,6)+	**.68**	2.26+
2	**Age (Months)**	.78	.69	**.38**	8.59 (1,5)*	**-.57**	-2.69*
	Mean Achievement					**.62**	2.93*
1	**Total Inattention Symptoms**	.06	-.09	.06	0.41 (1,6)	.25	0.64
2	**Full Scale IQ (estimated)**	.47	.26	.27	2.52 (1,5)	**.72**	1.95
	Total Inattention Symptoms					**.58**	1.59
3	**Age (months)**	.41	.17	.01	0.06 (1,5)	**-.61**	-1.70
	Total Inattention Symptoms					.09	0.24
4	**Full Scale IQ**	.78	.62	.24	4.35 (1,4)	-.06	-0.19
	Age					**-.57**	-2.42+
	Total Inattention Sxs.					**.67**	2.09
1							
Step 1	**Mean Achievement**	.70	.58	**.70**	5.80 (2,5)*	**.95**	3.61*
	Total Inattention Symptoms					**.48**	1.94
Step 2	**Interaction (Achiev.*Inatt.)**	.78	.62	.08	1.47 (1,4)	**.31**	1.21
2	**Mean Achievement**	**.70**	**.58**	**.24**	**3.97 (1,5)+**	**.84**	**3.25***
	Total Inattention Symptoms					**.52**	**1.99+**
3	**Total Inattention Symptoms**	**.70**	**.58**	**.64**	**10.54 (1,5)***	**.52**	**1.99+**
	Mean Achievement					**.84**	**3.25***

‡β after final step; *p≤ .05; + p≤.10

APPENDIX C

Ambiguous Words Task Instructions

Set-up directions:

1) Open "Lisa Dissertation" folder on desktop.
2) Open "Gernsbacher Task" folder.
3) Double click on icon for appropriate list (right now there is only one list—List C—soon there will be an A and a B list which we will rotate randomly—the cover page will tell you which list to administer when that occurs).
4) Click on the run button/
5) Enter subject id# and session # (always=1).
6) **Make sure the Y and N stickers are on the 1 and 3 keys and the "blank" sticker covers the N key used for another task).**

Directions:

Say:
I would like you to read some sentences silently to yourself. All of the sentences you will read end in a word that can have more than one meaning.

You know how the word "glass" can <u>either</u> be the thing you drink out of <u>or</u> the thing in your window? These sentences use words like glass. After you read the sentence, you need to decide whether each sentence makes sense for at least <u>one</u> of the meanings of the word. So, for example, if you read "He drank from the glass"—you would answer "yes"—the sentence makes sense. If you read "He broke the window glass," you would also answer "yes"—the sentence makes sense.

Now, in addition to these sentences that make sense, some of the sentences are "silly" sentences that don't make any sense at all—no matter which meaning of the word you use. So, for example, if you read, "He ate the glass"—you would answer "no"—that the sentence does not make sense—it is a "silly" sentence.

Press the "Y" key if the sentence makes sense and the "N" key if the sentence does not make sense. Be sure to respond as quickly and as accurately as you can.

Do you have any questions? [If child does not understand any aspects of the task, try to explain further].

Administer practice items—if child gets any of the items wrong—explain why they got it wrong and try to make sure they understand why it was wrong. Use this as a way to make sure the child understands the purpose/directions of the task.

After the practice say, "That was good. Now we're going to try the game 'for real'" Make sure to press the "Y" key if the sentence makes sense and the "N" key if the sentence does not make sense. Remember to answer as quickly and as accurately as you can.

There will be 5 blocks of sentences and you will have an opportunity to take a short break after each block.

Garden Path Instructions:

***Read these before the instructions on the screen*:**

Say: *You will read some sentences to yourself and will answer a question about each sentence. The most important thing for you to remember when you answer the questions is that your answer should be based only on the meaning of that specific sentence. You should never assume any information outside of the sentence itself. So, for example, if a question asks whether Jane baked a cake, you should answer yes only if the sentence specifically states that. If you think based on the sentence that Jane might have baked the cake sometime before, but the sentence doesn't specifically say that she did, then you should answer no, that Jane did not bake the cake.*

Also, be aware that many (but not all), of these sentences are "tricky" sentences—that is, they have two parts that are blended together. Because the 2 parts of the sentence are blended together, the sentence may seem to mean one thing, but really mean another. Your job is to figure out which parts go together and then answer the question based on that. You need to be careful and pay very close attention, because sometimes the answer that seems "obvious" is not actually the right answer. Also, keep in mind that sometimes the correct answer to the sentence may seem a little silly.

Let's try some for practice.

If the child gets any of the practice items wrong, ask him/her to explain why they thought their answer was right. Explain to them, using the directions, why that answer is not correct. E.g., point out that they made an inference outside the sentence context or that they were tricked by the way the sentence parts were blended.

APPENDIX D

Ambiguous Words Task Stimuli

PrimeList	Target	Condition
He had a sick organ.	He played the organ.	Different
He swung with the bat.	He saw the flying bat.	Different
He walked out onto the deck.	He sorted the deck.	Different
She heard the bark.	She cut the bark.	Different
She hurt her foot.	She jumped a foot.	Different
She lost her key.	She used the answer key.	Different
She made it to the top.	She tried to spin the top.	Different
She put more jam on the toast.	She held her cup for the toast.	Different
She put on the pretty ring.	She heard the loud ring.	Different
She sent the letter.	She sang every letter.	Different
She stole from the bank.	She fished from the bank.	Different
She wrote with the red pen.	She threw food into the pen.	Different
He ate on the calf.	He fed the calf.	Filler
He ate the mint.	He swam the mint.	Filler
He bit his lip.	He let his lip.	Filler
He broke his rib.	He led his rib.	Filler
He closed the jar.	He wrote the jar.	Filler
He did into the tie.	He put on his new tie.	Filler
He fed to a spade.	He played a spade.	Filler
He had to pay the bill.	He wanted to smell the bill.	Filler
He lay the box on its side.	He gave him for the side.	Filler
He let the bird go free.	He sent the car to free.	Filler
He put the books in a pile.	He met the cats to a pile.	Filler
He put the rake in the shed.	He fed the cup in the shed.	Filler
He ran in the race.	He planted the race.	Filler
He sang to the cape.	He had on a red cape.	Filler
He sat by the fire.	He sang on the fire.	Filler
He sat to fake the tag.	He went out to play tag.	Filler
He sent his mom a card.	He baked up the card.	Filler
He tied the dog to the post.	He ran to fan the post.	Filler
He used his brush.	He shot onto his brush.	Filler
He wanted to get a pet.	He cut to rake a pet.	Filler
He was a big fan.	He ended the fan.	Filler
He went to the game.	He saved to the game.	Filler
He went to the park.	He saved to the park.	Filler
She ate the ham.	She went the ham.	Filler

She ate the wake.	She sat the wake.	Filler
She baked up the state.	She saw a map of the state.	Filler
She came the spot.	She rang the spot.	Filler
She fed the bay.	She sang the bay.	Filler
She fell with the deep.	She backed with the deep.	Filler
She had gone the fine.	She sanded the fine.	Filler
She handed the face.	She let by the face.	Filler
She killed the store.	She went to the store.	Filler
She landed the will.	She baked the will.	Filler
She led the chip.	She fell the chip.	Filler
She met the stick.	She broke the stick.	Filler
She met to the frame.	She let the frame.	Filler
She played the well.	She did not feel well.	Filler
She raked the gas.	She stamped the gas.	Filler
She ran a cap.	She met a cap.	Filler
She rang on the band.	She rode the band.	Filler
She rang the plant.	She cut the plant.	Filler
She sanded the bug.	She went the bug.	Filler
She sang the fly.	She came the fly.	Filler
She sat the drop.	She asked the drop.	Filler
She shut the arm.	She broke her arm.	Filler
She shut the box.	She blamed the box.	Filler
She smelled a grade.	She got a good grade.	Filler
She spoke the nut.	She met for the nut.	Filler
She spoke the tip.	She fed to the tip.	Filler
She spun the land.	She rang the land.	Filler
She swam in the pool.	She called on the pool.	Filler
She swam the mass.	She fell the mass.	Filler
She tamed a file.	She rode on a file.	Filler
She used the yarn.	She sat the yarn.	Filler
She wanted to hide.	She hit by the hide.	Filler
She wanted to make a trade.	She sanded to rope a trade.	Filler
She went the fall.	She lay the fall.	Filler
She went the ship.	She baked the ship.	Filler
She woke the glass.	She went the glass.	Filler
She wrote the dip.	She played the dip.	Filler
He called the pipe.	He got water from the pipe.	Nonsense
He looked the case.	He got ready for the case.	Nonsense
He mopped the play.	He won the game with the play.	Nonsense
He walked the club.	He hit him with the club.	Nonsense
She fell a date.	She went out on a date.	Nonsense
She grew the ruler.	She saw the throne of the ruler.	Nonsense
She hiked the jam.	She ate the jam.	Nonsense
She hoped the drill.	She marched during the drill.	Nonsense

She lived a note.	She played a note.	Nonsense
She sang a seal.	She closed the letter with a seal.	Nonsense
She spoke the spring.	She broke the bed spring.	Nonsense
She told the nail.	She bit her nail.	Nonsense
She went the punch.	She was hurt by the punch.	Nonsense
NULL	NULL	NULL
NULL	NULL	NULL
NULL	NULL	NULL
NULL	NULL	NULL
NULL	NULL	NULL
He broke the water pitcher.	He filled up the pitcher.	Same
He cut off the cow's horn.	He looked at the ram's horn.	Same
He got a shorter jail sentence.	He was serving a life sentence.	Same
He mixed the batter.	He made the batter.	Same
He tied the red bow.	He undid the bow.	Same
He went into the bar.	He got a drink at the bar.	Same
She got dressed for the ball.	She danced at the ball.	Same
She hoped to be a big star.	She wanted to be a big star.	Same
She lit the match.	She blew out the match.	Same
She lived on the tenth story.	She went up to the tenth story.	Same
She sipped from the straw.	She drank from the straw.	Same
She threw out the pit.	She spit out the pit.	Same

Garden Path Stimuli

Condition	**Sentence**	**Question**
control-IP	The pup grew as Joe was cutting.	Was Joe cutting the pup?
control-IP	The robber was locked up as the kids played.	Did the kids play the robber?
control-IP	The rock got passed as Fran was writing.	Was Fran writing the rock?
control-IP	The snow got cold as Fred cooked.	Did Fred cook the snow?
control-IP	The worm swam in the lake as Jack ate.	Did Jack eat the worm?
control-P	The bus did not run as Sam drove.	Did Sam drive the bus?
control-P	The frog swam in the lake as the snake ate.	Did the snake eat the frog?
control-P	The girl was at the store as Tom kissed.	Did Tom kiss the girl?
control-P	The notes burned as Jill was reading.	Was Jill reading the notes?
control-P	The water cooked as Deb drank.	Did Deb drink the water?
coord-cont-IP	Ken talked to the boss and that's why the men were not at work.	Did Ken talk to the men?

coord-cont-IP	Sue kissed her mom and that's why her dad sat in the den.	Did Sue kiss her dad?
coord-cont-P	The girl played with the baby and that's why her mom helped.	Did the girl play with her mom?
coord-cont-P	The star kissed the fan and that's why her date got mad.	Did the star kiss her date?
coordination-I	Bob fed the cat and the dog was at the vet.	Did Bob feed the dog?
coordination-I	Mommy called the doctor and the nurse was out sick.	Did Mommy call the nurse?
coordination-I	The girl played with the baby and her mom went out.	Did the girl play with her mom?
coordination-I	The star kissed the fan and her date stayed home.	Did the star kiss her date?
coordination-P	Ken talked to the boss and the men did good work.	Did Ken talk to the men?
coordination-P	My sister bumped into the mailman and my mom told her to be careful.	Did my sister bump into my mom?
coordination-P	Peg hit the boy and the teacher told her to sit in the hall.	Did Peg hit the teacher?
coordination-P	Sue kissed her mom and her dad gave her a hug.	Did Sue kiss her dad?
filler	As Daddy made the food the kids played in the den.	Did Daddy make the tape?
filler	As Dan drove the car he sang to the tape.	Did Dan drive the bus?
filler	As Flo was jumping rope she hurt her foot.	Was Flo jumping the log?
filler	As Jake shot the bow the bird flew into the tree.	Did Jake shoot the bunny?
filler	As Jane ate the food her mom did the dishes.	Did Jane eat the food?
filler	As Jane was making the cookies her mom flew to Mars.	Did Jane's mom fly to Mars?
filler	As Mom told the story the boy lay in his bed.	Did Mom tell the cops?
filler	As Pam was feeding the fish she saw a frog.	Did Pam feed the fish?
filler	As Pam was feeding the fish she saw a UFO.	Did Pam see a UFO?
filler	As Sam played the drums his mom left the room.	Did Sam play the drums?
filler	As the boy hit the ball the dog ran to get it.	Did the boy hit the ball?
filler	As the boys were making the fire they put on more wood.	Were the boys making the cake?
filler	As the boys were making the kite they put on the tires.	Did the boys put on the tires?
filler	As the dog went for the cat the boy pulled	Did the dog go for the

	on its rope.	cat?
filler	As the girl played the fox her mom left the room.	Did the girl play the fox?
filler	As the kids sang the song the teacher played the piano.	Did the kids sing the song?
filler	As the man drove the cow he sang to the moon.	Did the man drive the cow?
filler	As the man shot the gun the ape flew into the tree.	Did the ape fly into the tree?
filler	Bob played in the den as his mom was baking the cake.	Was Bob's mom baking the ham?
filler	Spot ate the bone as the boy was feeding the cat.	Did the boy feed the dog?
filler	The baby drank the milk as it sat in the crib.	Did the baby sit in the crib?
filler	The bird flew into the tree as it looked for the nest.	Did the bird look for the cat?
filler	The boys took their books as they were leaving for school.	Were the boys leaving for the play?
filler	The boys took their pens as they left for jail.	Did the boys leave for jail?
filler	The cops saved the dog as the snake ate the home.	Did the snake eat the home?
filler	The dog hid the bone as it filled up the hole.	Did the dog fill up the hole?
filler	The fireman saved the cat as the fire burned the house.	Did the fire burn the house?
filler	The girl got the food as Tom sat at the table.	Did Tom sit at the table?
filler	The girl hid the bone as she made the cake.	Did the girl make the cake?
filler	The girl went to the park as she was riding her bike.	Was the girl riding the bike?
filler	The man had a dog as he left the bank.	Did the man have a dog?
filler	The man took the cash as he left the bank.	Did the man leave the home?
filler	The mom played the socks as she watched the news.	Did the mom play the socks?
filler	The mom sewed socks as she watched tv.	Did the mom watch tv?
filler	The pup drank the ink as it sat in the cage.	Did the pup drink the ink?
filler	The wife washed the dishes as the man cut the grass.	Did the man cut the note?
implausible	As Ben was writing the baby was on tv.	Was Ben writing the baby?
implausible	As Bill was eating the spoon baked in the	Was Bill eating the

	oven.	spoon?
implausible	As Buffy walked the bunny napped.	Did Buffy walk the bunny?
implausible	As Dan baked the milk shake tasted good.	Did Dan bake the milk shake?
implausible	As Deb rode the bear was sleeping in its den.	Did Deb ride the bear?
implausible	As Fred threw the cat sat still.	Did Fred throw the cat?
implausible	As Meg played the shoes got shined.	Did Meg play the shoes?
implausible	As Ned was reading the door was closed.	Was Ned reading the door?
implausible	As the ape ate the tree grew.	Did the ape eat the tree?
implausible	As the bird ate the tire lay in the dirt.	Did the bird eat the tire?
plausible	As Ann was eating the cake baked.	Was Ann eating the cake?
plausible	As Bill was running the race did not start due to rain.	Was Bill running the race?
plausible	As Bob hunted the deer hung on the wall.	Did Bob hunt the deer?
plausible	As Joe walked the dog napped.	Did Joe walk the dog?
plausible	As Pam baked the cake got stale.	Did Pam bake the cake?
plausible	As Ron drove the car sat in the lot.	Did Ron drive the car?
plausible	As the cat chased the rat sat still.	Did the cat chase the rat?
plausible	As the man cut the grass got long.	Did the man cut the grass?
plausible	As the storm blew the boat sat in the shed.	Did the storm blow the boat?
plausible	As Tom cooked the hot dog got cold.	Did Tom cook the hot dog?
RAT-cont-IP	The game was on tv as Mommy washed.	Did Mommy wash the game?
RAT-cont-IP	The kids swam in the pool as Frank dried off.	Did Frank dry off the kids?
RAT-cont-P	The baby was in bed as the boy washed.	Did the boy wash the baby?
RAT-cont-P	The cat sat on the bed as the man shaved.	Did the man shave the cat?
RAT-I	As Anna dressed the dog played ball in the yard.	Did Anna dress the dog?
RAT-I	As Daddy hid the baby was lost.	Did Daddy hide the baby?
RAT-I	As Daddy hid the kids looked for him.	Did Daddy hide the kids?
RAT-I	As the man shaved the cat sat in the tree.	Did the man shave the cat?
RAT-P	As Betty woke up Daddy was sleeping in the den.	Did Betty wake up Daddy?

RAT-P	As Frank dried off the kids got out of the pool.	Did Frank dry off the kids?
RAT-P	As Jan dried off the cat jumped onto the bed.	Did Jan dry off the cat?
RAT-P	As Mommy washed the cat came into the room.	Did Mommy wash the cat?

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