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Different time course of negative priming in the subtypes of ADHD

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Different time course of negative priming in the subtypes of ADHD

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Dedication

To my parents, Chanjoo Shin, Hwasun Kang, Jangho Lee, & Ockjin Lee,

my daughter, Hanna Lee,

and my husband, Chang Hoan Lee.

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Different time course of negative priming in the subtypes of ADHD

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The nature of inattention in attention deficit hyperactivity disorder (ADHD) and the issue of whether the inattentive ADHD type (ADHD/IA) represents a true subtype or a distinct condition still remain controversial in ADHD research. According to Barkley's theory of ADHD (1997), the combined ADHD type (ADHD/C) has deficits in behavioral rather than cognitive inhibition and inattentive symptoms in this subtype are secondary to behavioral inhibition. In contrast, he suggested the core deficit in the ADHD/IA type relates to selective attention, which is separate from behavioral inhibition. Studies of subtype differences in ADHD failed to differentiate the ADHD/IA type from the ADHD/C type although both subtypes were distinct from non-diagnosed controls. In this study, the time course of negative priming and facilitation was tracked using a letter-

matching and a localization task in order to investigate whether the ADHD/C and ADHD/IA subtypes would show different profiles of selective attention. College students with ADHD/C (n = 10 for the letter-matching task; n = 11 for the localization task), or ADHD/IA (n = 9 for both tasks), and the non-diagnosed controls (n = 14 for the letter-matching task; n =16 for the localization task) performed on two tasks with response-to-stimulus intervals (RSIs) of 500ms and 1000ms. Results indicated that the two ADHD subtypes had different profiles of negative priming on the letter-matching task, but they had similar facilitation profiles on both tasks. The study also addressed problems with negative priming studies in ADHD.

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Chapter 1

Introduction

Attention Deficit Hyperactivity Disorder (ADHD), one of the most commonly diagnosed childhood psychological disorders, affects 5-10% of school-aged children (Scahill & Schwab-Stone, 2000) and is characterized by symptoms of inattention (e.g., is easily distracted or forgetful), impulsivity (e.g., interrupts others), and hyperactivity (e.g., acts as if "driven by a motor") (DSM-IV, APA, 1994). Currently, three subtypes of the disorder have been identified: (1) the predominantly inattentive (ADHD/IA) subtype with significant impairment only in the area of inattention, (2) the predominantly hyperactive/impulsive (ADHD/HI)[1] subtype with significant hyperactive/impulsive symptoms, and (3) the combined (ADHD/C) subtype characterized by significant impairment in both symptom domains.

Although ADHD has historically been considered a childhood disorder, a growing body of research indicates that approximately one-third to two-thirds of child ADHD cases persist into adulthood (Gallagher & Balder, 2001; Mannuzza, Klein, & Bonagura, 1991; Shekim et al., 1990). While hyperactivity/impulsivity symptoms become less apparent with age, problems with attention and organization persist (Biederman et al., 2000; Gallagher &

[1] It is important to note that the ADHD/HI subtype has been newly introduced into the diagnostic system, and is still controversial (i.e., is it a precursor of the ADHD/C subtype or a unique subtype?). Therefore, the focus of the review will be on the ADHD/C and ADHD/IA types.

Balder, 2001). Further, adult ADHD is often associated with other psychiatric disorders, particularly substance abuse, antisocial behaviors, and anxiety and mood disorders (Biederman et al., 1993; Downey, Stelson, Pomerleau, & Giordani, 1997; Heiligenstein et al., 1999; Murphy & Barkley, 1996) and functional impairments in multiple domains including lower socioeconomic status, occupational difficulties, and interpersonal problems (Barkley, Murphy, & Kwasnik, 1996).

Despite numerous studies, the development of a unified theory of ADHD has been impeded by frequent changes in nomenclature and the resulting confusion. The subtyping issues have centered on whether ADHD is best conceptualized in uni-dimensional (DSM-II, 1968; DSM-III-R, 1987) or multidimensional (DSM-III, 1980; DSM-IV, 1994) terms. With regard to core deficits, two major trends emerge. One emphasizes inhibitory deficits as a defining feature (Barkley, 1997; Pennington & Ozonoff, 1996; Quay, 1988; Schachar & Logan, 1990), and the other places more weight on problems with attention (Douglas, 1972; Mirsky et al., 1996; Posner & Raichle, 1994; Seargeant, Oosterlann, & Van der Meere, 1999). The nature of inattention in ADHD and the status of the ADHD/IA subtype within the larger context of the disorder (i.e., whether it represents a true subtype or a distinct condition) still remain controversial in ADHD research (Barkley, 1997; see Barkley, 2001b for the most recent debate). It is important to note that these theories are based mostly on studies of childhood ADHD and the ADHD/C subtype and do not incorporate research on adult ADHD and/or the ADHD/IA subtype.

With the publication of the influential book, *ADHD and the Nature of Self-control* (Barkley, 1997), the focus of ADHD research has shifted from examining deficits in attention to deficits in behavioral inhibition in ADHD. However, the ADHD/C and ADHD/IA types only share inattentive symptoms according to DSM-IV; thus, understanding the nature of inattention in ADHD

might be of particular importance in differentiating these subtypes (Nigg, 2001). Further, because inattentive symptoms persist into adulthood whereas hyperactive/impulsive symptoms generally decay, examining inattention in adult ADHD might lead to a clearer understanding of subtype differences. One important aspect of inattention is a deficit in selective attention—the ability to attend to relevant information while ignoring irrelevant information. For example, selective attention is necessary to effectively listen to a speaker when background noises or conversations are simultaneously occurring. Given that Barkley (1997) posited selective attention is at the core of inattention in the ADHD/IA type but not the ADHD/C type, investigating profiles of selective attention might reveal important clues as to how the subtypes differ.

A negative priming paradigm has been commonly used to specifically investigate cognitive inhibitory processes underlying selective attention in different populations. Since this paradigm is thought to measure the inhibitory aspect of selective attention, it can test not only the notion in Barkley's theory that the ADHD/C type has deficits in behavioral rather than cognitive inhibition but also whether the core deficit in the ADHD/IA type, unlike the ADHD/C type, is related to selective attention.

The purpose of the current study was to investigate the nature of inhibitory processes underlying selective attention in the ADHD/C and ADHD/IA types of college students using two tasks that involve negative priming. In the following sections, the nature of inattention and inhibitory deficits in ADHD will be reviewed. From that context, the focus will narrow to a review of neuro-cognitive profiles of ADHD, with an emphasis on subtype differences. In the final section, the negative priming paradigm will be discussed along with a review of the ADHD studies using this paradigm.

Chapter 2

2.1 The nature of inattention and inhibitory deficits in ADHD

2.1.1 Barkley's model of ADHD

The most researched inhibition-based model of ADHD is Barkley's (1997). The major tenet of his theory is that ADHD is a disorder that stems from deficits in behavioral inhibition and is mediated by the prefrontal cortex. Barkley postulated that the inattentive symptoms in the ADHD/C type are characterized by poor sustained attention (i.e., the inability to maintain attention over time) and deficient interference control (i.e., difficulty resisting conflicting responses /distractibility), both of which arise from deficient behavioral inhibition. Accordingly, inattentive symptoms are thought to be secondary to deficits in behavioral inhibition in hyperactivity and impulsivity. With regard to the nature of inattention in the ADHD/IA type, based on factor analytic studies and EEG findings, Barkley postulated that individuals with this subtype might have a deficiency in focused or selective attention. In his model, selective attention was thought to be related to early stage of processing and primarily was based on cognitive inhibition, distinct from behavior inhibition. Thus, Barkley considered the ADHD/IA type to be qualitatively different from the ADHD/C type and excluded it from his inhibition-based model.

Major evidence supporting his theory comes from studies using the Continuous Performance Task (CPT), the Stop Signal task, and the Stroop task. Different versions of CPTs have been developed but all are experimenter-paced

tasks in which participants are presented with a sequence of stimuli (e.g., letters or digits) and required to detect a predefined target. Two types of errors made on CPTs are omission errors (i.e., a failure to respond to a target) and commission errors (i.e. inappropriate responding to a non-target). Omission errors have been thought to be associated with difficulty with vigilance (i.e. the ability to stay alert when the probability of a target is low) or sustained attention whereas commission errors have been associated with response inhibition or impulsivity. CPT studies have found that, relative to non-disordered children, children with ADHD made more errors of commission and/or omission on the CPT (Barkley, Grodzinsky, & Dupaul, 1992; Hooks, Milich, & Lorch, 1994; Losier, McGrath, & Klein, 1996).

In addition to the CPT, the Stop Signal task has been considered to measure inhibition of a prepotent response. This task consists of go and stop trials. On go trials, participants are instructed to respond to symbols (usually letters) presented on a computer screen. On 25% of the trials, participants are asked to withhold their responses to symbols when an auditory tone is presented after the display of symbols. These stop trials are interspersed randomly and the intervals between the go stimulus and the stop signal are variable. The Stop Signal Reaction Time (SSRT) is derived from subtracting the mean delay from the mean reaction time on go trials (Go RT). Other dependent variables measure processing speed, accuracy, and variability of responding. Studies based on the stop signal paradigm have found that children with ADHD, compared to non-disordered children, tended to be slower and more variable in go trials and/ or take longer to inhibit their responses to stop signals (Oosterlaan & Sergeant, 1995; Schachar, Tannock, Marriott, & Logan, 1995).

Finally, the Stroop task has been thought to be a reliable and specific method for differentiating children with ADHD from those without ADHD

(Barkely, Grodzinsky, & Dupaul, 1992; Barkely, 1997; Seidman et al., 1997). The Stroop task is a timed test in which subjects are asked to name the ink colors printed in three different conditions: neutral (e.g., the word "red' printed in black ink), congruent (e.g., the word "red" printed in red ink), and incongruent (e.g., the word "red" printed in blue ink). Studies using the Stroop task have shown that children with ADHD took more time and made more errors than normal children. Placed in Barkley's model, these results were interpreted as reflecting difficulty with interference control. The ability to resolve conflicting responses (reading color words versus naming the ink color) is related to process of response selection and a later stage of processing whereas selective attention is related to an early stage of processing as in the ADHD/IA type. In Barkley's model, interference control is primarily based on behavioral inhibition.

In sum, according to Barkley's model, inhibitory problems in children with ADHD/C are characterized by impulsivity (poor response inhibition), as evidenced by more errors of commission on the CPT and slower SSRT on the Stop Signal task, poor sustained attention/vigilance as indicated by more omission errors, and deficient interference control, as reflected by more errors and more time on the Stroop test. The inattentive symptoms in the ADHD/C type are likely due to deficits in sustained attention and interference control, which are secondary to deficits in behavior inhibition. On the contrary, the inattentive symptoms in the ADHD/IA type are purportedly due to deficits in selective attention, which are primarily related to cognitive inhibition. Thus, the ADHD/IA type is considered to be qualitatively different from the ADHD/C type and is excluded from the model.

Contrary to the notion that the ADHD/IA type is mainly related to deficits in selective attention and unrelated to behavior disinhibition, studies using the CPT, the Stop Signal task, and the Stroop task consistently failed to

show differences between the ADHD/C and ADHD/IA types (see 2.2.2 & 2.2.3 for detailed discussion.) Further, some studies reported deficits selective attention in the ADHD/C type (Brodeur & Pond, 2001). Thus, the relationship between behavioral and cognitive inhibition in subtypes of ADHD might not be as clear as Barkley postulated. In the following section, Nigg's taxonomy of inhibitory processes will be reviewed with a focus on subtyping issues to further clarify the nature of inattention in ADHD subtypes.

2.1.2 Nigg's taxonomy of multiple inhibitory processes

In his recent review of the ADHD literature, Nigg (2001) made an attempt to clarify the complexity of inhibitory processes by proposing a taxonomy to describe the nature of inhibitory deficits in ADHD. He argued the distinction between executive and motivational inhibitory processes was the most relevant to theories of ADHD. Nigg defined executive inhibition as a controlled process (a top-down or downstream process) of suppressing an irrelevant cognition or response to achieve a future-oriented goal mediated by prefrontal areas. In contrast, motivational inhibition was referred to as a suppression of a behavior or a response in the presence of a signal for danger or punishment mediated by sub-cortical neuro-circuitry (a bottom-up or upstream process).

Nigg concluded that symptoms of ADHD might result from an executive inhibitory control deficit, rather than a motivational deficit. Executive inhibition was further broken down into subcomponents of behavioral inhibition and cognitive inhibition. According to the cognitive/ developmental psychology literature (see Harnishfeger, 1995, for a review), behavioral inhibition is referred to as the control of overt behavior such as delay of gratification, motor inhibition, and inhibiting impulsive behavior whereas

cognitive inhibition involves suppressing task-irrelevant contents or processes. It has been suggested that behavioral inhibition usually develops earlier than cognitive inhibition. These two processes are considered to be different, but clearly related. For example, studies have found that cognitive inhibition can be used to facilitate behavioral inhibition (e.g., delay of gratification; Mischel Shoda, & Rodriguez, 1989; Wegner, 1989).

With regard to subtype differences, Nigg suggested that the putative psychological dysfunction of the ADHD/IA type could also be inhibitory, even though the cognitive deficits of the ADHD/IA type might be different from those of the ADHD/C type. Further, he speculated that the ADHD/IA type might have an executive deficit in cognitive inhibition, whereas the ADHD/C type might have an executive deficit in behavioral inhibition.

Drawing evidence for his taxonomy, he focused on neuro-cognitive tasks that showed some data for measuring inhibitory control. Some of the key tasks for behavior inhibition included the go/no-go, Stop Signal, and antisaccade tasks measuring for inhibition of motor response, and the Stroop task reflecting interference control. Tasks measuring cognitive inhibition included directed forgetting and negative priming tasks.

2.1.3 Limitations of inhibition based models in the case of subtypes of ADHD

Whereas Barkley (1997) postulated that the ADHD/C type has deficits in behavioral inhibition but not in cognitive inhibition, Nigg argued that the association between the ADHD/C and deficits in cognitive inhibition remains unclear. As for subtypes of ADHD, Nigg suggested the use of a more specific measure for investigating cognitive inhibition in the ADHD/C as well as ADHD/IA types. In his recent study (Nigg, Butler, Huang-Pollock, &

Henderson, 2002), Nigg et al. used the antisaccade task as a measure for motor inhibition and the negative priming task as a measure for cognitive inhibition to test the hypothesis that the ADHD/C type would display a deficit in motor inhibition but not in cognitive inhibition. The results confirmed his hypothesis. However, the failure to find the cognitive inhibition deficit in the ADHD/C type might be related to task parameters (e.g. response to stimulus interval, presentation time of stimulus, etc.) rather than an indication of an intact inhibitory mechanism (see 2.3.3 for a detailed discussion). Standard negative priming effects are small (20ms) and a great variability in clinical groups makes it harder to detect these effects (Hoenig, Hochrein, Muller, & Wagner, 2002). Thus, changes in tasks parameters and the choice of negative priming tasks might yield different results. Further, the ADHD/IA type was not included in the study, limiting the findings to the ADHD/C type.

An alternative way of examining subtype differences in cognitive inhibition is that although both ADHD/C and ADHD/IA types show similar cognitive deficits, the underlying processes might be different. Researchers have found that both cognitive failure (i.e., forgetfulness and distractibility) and absorption (i.e., the tendency to become immersed in inner experience) are related to inefficient cognitive inhibition. Although characteristics of cognitive failure can be found in both ADHD/C and ADHD/IA types, it is possible that underlying mechanisms differ according to subtypes. In the case of ADHD/C, for example, an under-active inhibitory mechanism might underlie attentional deficits, whereas an overactive mechanism might trigger similar, but inattentive, symptoms in the ADHD/IA subtype. As for the lack of differences in cognitive inhibition in children with ADHD might reflect a developmental lag, given that behavioral inhibition usually develops earlier than cognitive inhibition. It also seems reasonable to speculate that children both with ADHD and without ADHD might not show differences in cognitive inhibition due to

their still developing brains. Thus, differences in cognitive inhibition might emerge as they grow older.

In subsequent sections, the neuropsychological profiles of ADHD will be reviewed first along with subtype differences in ADHD. Then, the extant research literature on negative priming in ADHD will be reviewed in detail in order to examine the nature of cognitive deficits in subtypes of ADHD.

2.2 Neuro-cognitive profiles of ADHD

2.2.1 Overall findings with adults

Given that the issue of the diagnostic continuity of pediatric ADHD into adulthood is still controversial, generalizing findings from children to adults can be problematic. In general, however, studies using neuropsychological tasks in adult ADHD show similar profiles to those of childhood ADHD. The scope of this review will be focusing on measures considered to tap inhibitory function since the present study was to examine inhibitory mechanism in subtypes of ADHD. Those measures include the CPT, the Stop Signal task, and the Stroop test.

CPT studies

The first line of research based on the CPT was consistent with prior research in children, suggesting that adults with ADHD, relative to non-disordered controls, may have deficits in response inhibition as indicated by more commission errors and/or sustained attention as indicated by greater standard deviation and omission errors (Barkley et al., 1996; Buchsbaum et al., 1985; Epstein, Johnson, Varia, & Conners, 2001; Gansler et al., 1998; Gualtieri et al, 1985; Holdnack, Moberg, Arnold, Gur, & Gur 1995; Klee et al., 1986;

Ossmann and Mulligan, 2003; Seidman et al., 1998). It should be noted, however, that studies using psychiatric controls to examine the specificity of the test found no differences between groups (Downey et al., 1997; Kovner et. Al, 1998; Riordan et al., 1999; Walker et al., 2000) except one study (Epstein et al., 2001). Epstein et al. (2001) compared the performance of adults with ADHD, adults with anxiety disorders, and normal controls on the Conners' CPT and found that, relative to both anxiety-disordered adults (effect size d = .75) and normal controls (d = .71), adults with ADHD made more commission errors. Inconsistent with the notion that different versions of the CPT have not proven effective in differentiating ADHD from other psychiatric controls (Gallagher & Blader, 2001), this finding was interpreted as evidence for a response inhibition deficit specific to ADHD and not to other psychiatric control groups (e.g., anxiety disorders).

Findings based on the CPT paradigm should be interpreted with caution for three reasons. First, variations in task parameters (e.g., presentation rate, stimulus type, task length, etc.) make generalizations about performance data difficult (Losier et al., 1996; Riccio & Reynolds, 2001). Second, the meaning of error types (i.e. omission error as an index for lack of vigilance and commission error for response inhibition deficit or impulsivity lacks sufficient empirical support (Nigg, Hinshaw, & Halperin, 1996). And, finally, because the CPT is sensitive to central nervous system (CNS) dysfunction, and thus performance deficits are manifested in multiple disorders, the specificity of the test needs further investigation (Riccio & Reynolds, 2001).

Stop Signal Task studies

Along with the CPT, the stop signal paradigm has been used as a measure of response execution (reflected by RT to the "go" signal) and response inhibition [indicated by Stop Signal Reaction Time (SSRT)].

According to meta-analytic studies (Nichols & Waschbusch, 2004; Oosterlaan et al., 1998) children with ADHD, relative to normal controls tended to be slower in SSRT by about 100ms (d = .64). On the contrary, studies with adults with ADHD yielded mixed results. Two studies found no differences between ADHD and normal controls (Epstein et al., 2001; Scheres, Oosterlaan, & Sergeant, 2001). Two studies (Murphy, 2002; Ossmann and Mulligan, 2003) reported slower SSRT in adults with ADHD compared to normal controls. As for specificity, Epstein et al. (2001) failed to find differences between ADHD and anxiety-disordered patients.

Stroop studies

Another line of research using the traditional card version of the Stroop test indicated that adults with ADHD, relative to controls, had slower mean reaction times on the color-naming (Corbett & Stanczak, 1999), took longer to complete the test (Hopkins, Perlman, Hechman, Weiss, 1979), completed fewer items (Lovejoy et al., 1999), and showed higher interference scores (the difference between the expected color word score and the color word score) (Taylor & Miller, 1997). These findings were in line with those for children (Barkley et al., 1992; Boucugnani & Jones, 1989; Carlson et al., 1986; Gorenstein et al., 1989; Grodzinski & Diamond, 1992; Leung & Connolly, 1996; Seidman et al., 1997; Semrud-Clikeman et al., 2000). In ADHD research, the Stroop test is considered to be related to interference control (Barkley, 1992; Nigg et al., 2001; Pennington and Ozonoff, 1996; Sergeant, Geurts, & Oosterlaan, 2002). In the study that assessed the diagnostic utility of the Stroop test, Lovejoy et al. (1999) reported that overall the test was able to discriminate adults with ADHD from normal controls (*Chi*-square = 9.1 $p < .01$). Further, the test was able to detect 23% of adults with ADHD (i.e., sensitivity) but unable to detect 43% of those who met for ADHD (i.e., false negative).

Of particular note is that these Stroop effects are not specific to ADHD. Individuals with schizophrenia (Perlstein, Carter, Barch, & Baird, 1998; Schooler, Neumann, Caplan, & Roberts, 1997), individuals with left frontal lobe lesions, and mildly and moderately demented patients (Lezak, 1995) also showed these Stroop effects. Studies that used the psychiatric controls failed to show differences between adults with ADHD and various psychiatric control groups (Downey et al., 1997; Taylor and Miller, 1998; Walker et al., 2000) except one study (Katz, Wood, Goldstein, Auchenbach, & Geckle, 1998). Katz et al. (1998) compared the performance of adults with ADHD to that of adults with depression on cognitive tests of attention span and memory, and found the Color Naming and Interference scores on the Stroop test (Golden, 1978) to be effective in differentiating the two groups when combined with other tests including the Paced Auditory Serial Addition Test (PASAT) and the California Verbal Learning Test (CVLT).

With the recent development of a single-trial version of the Stroop task, the methodology used in the traditional card version has been challenged (Perlstein et al., 1998). A typical card version of the Stroop consists of lists of color words printed in black ink, color patches, and color words printed in incongruent colors. Each condition is presented in a block format, comprising different columns. In a single trial version, stimuli are presented one at a time on a computer screen and different conditions are presented randomly. Comparing the performance of schizophrenics on card and single-trial versions of the Stroop, Perlstein et al. concluded that the single-trial version provides greater sensitivity to attentional pathology for several reasons. First, the card version introduces nonspecific sources of interference by requiring subjects to scan the list from column to column. Also, reaction times and errors are confounded in the card version, because subjects are instructed to correct their responses while they are timed. Consequently, poor performance is due to slow

correct responses and/or a greater number of errors. Finally, the blocked presentation of stimulus conditions in the card version, compared to random presentation of stimulus in different conditions, facilitates set effects

One study tested children with ADHD using a single-trial version of the Stroop test (Carter, Krener, Chaderjian, Northcutt, & Wolfe, 1995). In contrast to studies that used a card version, Carter et al. found that, relative to normal children, children with ADHD did not take longer to respond, nor make more errors in any conditions, but showed greater interference as measured by difference scores (the mean reaction time for interference condition – the mean reaction time for the neutral condition). Consequently, they were able to rule out scanning deficits and general slowing of responses as an explanation for greater interference in children with ADHD.

Two studies used the single trial version of the Stroop test in adult ADHD (Bush et al., 1999; Nigg et al., 2002). Nigg et al. reported that adults with ADHD compared to normal control, was slower in the Interference Condition ($p < .05$). However, the test did not include either word reading or color naming condition, providing no information on baseline performance. Thus, slower RT could be related to overall slowing. Another study using a single-trial version of the Counting Stroop (a Stroop variant) in adults with ADHD (Bush et al., 1999) failed to show a greater interference effect in the ADHD group compared to controls as measured by mean reaction times. However, fMRI results during the Counting Stroop showed a significant hypoactivation in the anterior cingulate cortex in the ADHD group relative to controls. The failure to detect group differences in the behavioral data might be due to the small number of subjects (8 subjects for each group).

Studies using other tasks

In addition to measures of inhibition, studies using other tasks indicated that, relative to normal controls, adults with ADHD might be impaired in other functions, including: (1) verbal learning as measured by the CVLT (Downey et al., 1997; Holdnack et al., 1995; Katz et al., 1998; Seidman et al., 1998), (2) perceptual motor speed as measured by the digit symbol and coding tests (Holdnack et al., 1995; Silverman et al., 1995), (3) working memory as assessed by the digit span tests (Barkley et al., 1996; Holdnack et al., 1995) and (4) spatial working memory as measured by delayed oculomotor response task (Ross et al., 2000) and the Cambridge Neuropsychological Test Automated Battery (CANTAB) version of spatial working memory (Dowson et al., 2003). In contrast, studies using the Wisconsin Card Sorting Test (WCST), a task considered to be tapping concept formation and set shifting, consistently found no differences between the ADHD and the control groups (Gansler et al., 1998; Holdnack et al., 1995; Seidman et al., 1998). These findings were also inconsistent with those with children.

Summary

In sum, adults with ADHD, relative to normal controls, showed deficits on the CPT, the CVLT, the digit symbol, coding, and digit span tests from the WAIS-R, and the Stroop test, but no differences on the WCST. Study findings based on the CPT and card version of the Stroop test seemed to be consistent with those with children with ADHD. It should be noted, however, that studies using the single trial version of the Stroop task yielded mixed results. The Stop task has not been used with adult populations as much as with child populations. These studies showed inconsistent results. As for specificity of findings compared to other psychiatric conditions, deficits associated with the

CPT seemed to be able to differentiate at least those associated with anxiety disorders. Deficits reflected by the Stroop test seemed to be able to differentiate ADHD from depression when the test was combined with other tests. There was no difference in performance on the Stop Signal task between ADHD and anxiety disorders. Overall, specificity of results on various neuro-cognitive tests is low, making it hard to understand deficits uniquely associated with ADHD.

In the following sections, subtype differences in ADHD will be reviewed in detail in an attempt to identify neuro-cognitive profiles specific to subtypes of ADHD. Given that most research has been conducted with children, studies investigating childhood ADHD will be reviewed before adult ADHD studies.

2.2.2 Subtype differences in childhood ADHD

Studies of the neuropsychological profiles of children with DSM-IV subtypes showed inconsistent results. Two studies reported subtype differences whereas three did not support subtype differences. Klorman et al. (1999) found that children with the ADHD/C type, relative to those without ADHD, exhibited deficits in planning ability as measured by the Tower of Hanoi, whereas children with ADHD/IA did not differ significantly from controls on the same measure. Nigg et al. (2002) compared neuropsychological profiles of children with ADHD/C, children with ADHD/IA, and community controls in the areas of behavioral inhibition as measured by the Stop Task, planning as measured by the Tower of London, interference control as measured by the Stroop test, set-shifting as measured by Trail Making B, and response speed as measured by the Go RT on the Stop task, Color Naming on the Stroop, and Trail Making A. Both subtypes exhibited deficits on output speed in comparison to controls, though ADHD subtypes did not exhibit differences on any of these measures. However, there was a group-by-gender interaction on

the Stop Task. That is, boys with ADHD/C performed more poorly relative to boys with ADHD/IA, whereas the performance of girls did not differ among subtypes. In addition, when IQ scores were covaried, the ADHD/IA group performed more poorly on Trail Making A in comparison to the ADHD/C group.

In contrast to studies supportive of subtype differences, three studies failed to show subtype difference. First, Houghton et al. (1999) found that the ADHD/C and ADHD/IA subtypes did not differ significantly on measures of inhibition, planning, and set-shifting, although both types showed significant deficits on these measures in comparison to controls. Second, in a large study of clinically referred children, Chabildas, Pennington, & Willcut (2001) examined the neuropsychological profiles of children without ADHD and children who met the symptom criteria for DSM-IV ADHD/IA, ADHD/HI, and ADHD/C subtypes in the areas of inhibition as measured by commission errors on the Gordon Diagnostic System (GDS; Gordon & Mettelman, 1988) and the Stop Task (Logan, Cowan, & Davis, 1984), processing speed as measured by the Trail Making Test (Reitan & Wolfson, 1985) and the Coding Subtest from the WISC-R (Wechsler, 1974), and vigilance as measured by omission errors on the GDS., They hypothesized that the ADHD/IA and ADHD/C subtypes would both show deficits in processing speed and vigilance since they share symptoms of attention, but only the ADHD/C subtype, would show inhibitory deficits. Contrary to prediction, the subtypes did not differ on any of these measures. Third, one community-based study (Scheres et al, 2001) using a stop signal paradigm did not find subtype differences in response inhibition measure as indicated by SSRT and the ADHD group as a whole did not show differences from normal controls although the ADHD group was slower as measured by Go RT and more variable reflected by standard deviation of Go RT.

Two studies based on DSM-III criteria using the Stroop test found no significant differences between ADD with hyperactivity and ADD without hyperactivity groups, although the ADD groups, relative to normal controls, took longer to complete the test (Carlson et al., 1986) and performed more poorly on the word reading and interference conditions (Barkley et al., 1992). One study comparing performance on the Stroop of children with ADHD subtypes based on DSM-IV criteria (Nigg et al., 2002) found that the two subtypes did not differ significantly from one another, although both groups exhibited slower naming speed than normal controls. All card version.

Summary

Overall, most neuropsychological tasks failed to differentiate the ADHD/C type from the ADHD/IA type, though some of those tasks (the Stroop test, the CPT, and the WCST) differentiated both subtypes from normal controls. Of particular note is that all measures considered to be related to different aspects of inhibitory mechanism failed to differentiate the ADHD/C type from the ADHD/IA type. The finding that even the ADHD/IA type showed deficits in behavior inhibition measures including the CPT, the Stop signal task, and the Stroop task raises questions about the validity of these tasks, subtyping issues, or heterogeneity within subgroups.

2.2.3 Subtype differences in adult ADHD

To date, four studies of subtype differences in performances of adult ADHD on neuropsychological tasks have been identified (Dinn, Robbins, & Harris, 2002; Epstein et al., 2001; Gansler et al., 1998; Taylor and Miller, 1997). Studies found no subtype differences in the CPT, Go/No-go task, and the Stop Signal task. Performance of subtypes in the WCST and the Stroop test showed mixed results.

In their clinic-based study, Gansler et al. (1998) hypothesized that adults with ADHD/HI would have problems at the organizational level of working memory mediated by the dorsolateral prefrontal system, whereas adults with ADHD/IA would have greater difficulty with specific content aspects of working memory mediated by the inferior frontal cortex. To test these hypotheses, they compared adults with ADHD/HI to adults with ADHD/IA on the Auditory Consonant Trigrams Test (ACT; also known as Brown-Peterson task), the WCST, and the U. Penn. Smell Identification Test. The ACT assessed how many units of information could be held in short-term memory given some interference (a lower-order "information specific" aspect of working memory), the WCST assessed a higher-order (monitoring) working memory, and the olfactory task tapped inferior frontal function. The data supported their hypotheses. Specifically, in comparison to the ADHD/IA group, the ADHD/HI group showed more deficits on the WSCT as indicated by an increased number of perseverative errors. The ADHD/IA group, relative to the ADHD/HI group, performed worse on the ACT as indicated by the fewer number of consonants they could recall at a brief delay of 9 or 18 seconds. Finally, the ADHD/IA group performed significantly below the level of the ADHD/HI group on the olfactory task.

Dinn, Robbins, and Harris (2001) compared the performance of 25 adults with ADHD (4 with ADHD/HI; 8 with ADHD/IA; 13 with ADHD/C) to that of 11 normal controls on a neuropsychological battery including measures considered to be sensitive to either orbito-frontal or dorsolateral-prefrontal (DLPF) dysfunction. They hypothesized that (1) the ADHD/HI type would display performance deficits on orbito-frontal tasks, (2) the ADHD/IA type would exhibit deficits on DLPF measures, and (3) the ADHD/C type would display poor performance on both orbito-frontal and DLPF measures. Orbito-frontal measures included the Object Alternation Test (OAT; Freedman, 1990),

the Stroop test, and a Go/No-Go task (based on Lapierre et al., 1995). Putative measures for DLPF dysfunction included the Controlled Word Fluency Test (Goodglass & Kaplan, 1972) and a divergent thinking task (Lezak, 1995).

Their hypotheses were partially confirmed. First, the ADHD/HI type, relative to controls, showed significant impairment on the OAT, but not on other orbito-frontal and DLPF measures. Second, the ADHD/IA type, relative to controls, did not show performance deficits on the OAT and the Stroop test, whereas they showed impairments on the Go/No-Go task (orbitofrontal) and the DLPF measures. Third, the ADHD/C type displayed trends for performance deficits on the Go/No-Go task and the conflict blocks of the Stroop test, both of which were taken to be orbito-frontal measures. In addition, the ADHD/C group generated significantly fewer words on the word fluency test, which was a part of the DLPF measures. These findings together were interpreted as evidence for the validity of ADHD subtypes mediated by abnormalities in functionally and anatomically distinct subdivisions of the prefrontal region.

In another study of subtype differences, Taylor and Miller (1997) compared adults with ADHD to adults with other psychiatric conditions (e.g., anxiety, mood, substance use, etc.) on the WCST, the Stroop test, the Trail Making Test (parts A & B), and the WAIS-R. The ADHD subgroups did not differ on any of these measures. However, in comparison to the ADHD/HI group, the ADHD/IA and ADHD/C groups showed more attentional deficits as measured by the Attentional Impairment (AI) index, which was based on performance on the WSCT, Stroop, and Trail Making tests. This finding was interpreted as evidence for the continuity of the ADHD subtypes into adulthood. It is important to note that there was a significantly positive correlation between the AI index and the number of psychiatric diagnoses, indicating attentional impairments for other psychiatric conditions beyond ADHD.

Finally, Epstein et al. (2001) compared performance of subtypes of ADHD on response inhibition measures including CPT, Stop Signal task, and Posner Visual Orienting Test. No subtypes differences were emerged on any of three tests.

Summary

In sum, studies seemed to fail in delineating coherent profiles of deficits specific to the subtypes. That is, in the Gansler et al. Study (1998), the ADHD/IA type showed deficits associated with the inferior frontal cortex (ACT and olfactory task), but not those associated with the dorso-lateral prefrontal system (WCST). In contrast, in the Dinn et al. Study (2001), the ADHD/IA type showed deficits associated with dorso-lateral prefrontal functions indicated by CWFT and divergent thinking. One could argue that different putative measures used for each study can explain the discrepant findings. Of more importance is that validity of neuro-cognitive measures seems to be far from well-established.

Both subtypes of children and adults with ADHD showed deficits on the CPT, Stop Signal task, and the Stroop task, which are considered to measure inhibitory processes. According to Barkley's theory and Nigg's taxonomy, the ADHD/IA type was not expected to show deficits on these behavioral inhibition measures. In the following sections, negative priming in ADHD will be reviewed, with a focus on the potential of this paradigm to differentiate subtypes of ADHD.

2.3 Negative priming in ADHD

2.3.1 Negative priming paradigm in selective attention

Selective attention is the ability to attend some stimuli while ignoring others (Payne & Wenger, 1998). Early models on selective attention focused on explaining the facilitatory aspect of selective attention of the relevant information and did not address issues over how irrelevant information is ignored and what happens to ignored information.

The term *negative priming* was originally introduced to describe the inhibitory effect of ignored stimuli, as opposed to the facilitatory effect of attended stimuli during selective attention tasks (Tipper, 1985). A modified Stroop task was used in the first demonstration of the negative priming effect. In contrast to the regular Stroop task, in which ink color and words are paired randomly, in the negative priming condition, the distractor on the first trial in a pair called prime trial is used as a target on the subsequent, or probe, trial. For example, the word *blue* written in green ink is followed by the word red in *blue* ink, and thus, the stimulus to be ignored in the prime trial (*blue*) is the correct response in the probe trial. Response times tend to be longer in the negatively-primed Stroop task than in the regular Stroop task. This slower response has been interpreted as indicating that ignored stimuli have to be actively inhibited on the prime trial. Accordingly, the response is slowed on the probe trial because the suppressed response has to be freed from inhibition.

Different types of negative priming tasks have been developed to examine generality of negative priming effects. Studies showed that negative priming effects occur in a variety of tasks including identification, categorization, matching, and localization tasks. First, identification tasks involve vocally naming the target (picture, word, or letter) in a certain color (red or green) or pressing the key that corresponds to the target letter presented in a certain color. Negative priming occurs when the stimulus associated with a distractor color becomes the target. Second, categorization tasks involve semantic categorization and lexical decision tasks. In semantic categorization

tasks, subjects are instructed to vocally respond with the super-ordinate category name (animal, furniture, etc) appropriate to target words specified by color. In lexical decision tasks, subjects are asked to make a judgment about whether each string of letters is a word or a non-word. Third, matching tasks involve judgments about whether letters or shapes are the same or different. Fourth, the negative priming effect in localization tasks is reflected in slower responses to a probe target that appears in the location of a prime distractor. The current study used matching and localization tasks to examine negative priming in the ADHD subtypes.

The negative priming paradigm has been used to examine cognitive profiles in a number of clinical and non-clinical groups. Reduced negative priming has been suggested in children, elderly people, individuals with depression, individuals with schizophrenia, individuals with anxiety disorders, and individuals with ADHD. On the contrary, enhanced negative priming has been suggested in a subgroup of OCD (Hoenig, Hochrein, Muller, & Wagner, 2002) and individuals with Parkinson's disease (Scott et al., 2002).

Houghton and Tipper (1994) suggested that inhibitory control is weaker in the elderly and children, relative to young adults. Attenuated negative priming was reported in individuals with depression (MacQueen, Tipper, Young, Joffe, & Levitt, 2000), as well. This deficit in distractor inhibition is thought to underlie selective attention deficits observed in depressed people. In their study of cognitive inhibition in individuals with schizophrenia, Beech et al. (1989) found a reduced negative priming effect only under 100ms presentation time. This finding was interpreted as reflecting weakened inhibition operating in the early stages of processing. It should be noted, however, that there have been debates over whether reduced negative priming in schizophrenia may be due to perceptual deficits (Moritz et al., 2001) or a deficit in cognitive inhibition (MacQueen, Galway, Goldberg, & Tipper, 2003).

MacQueen et al. (2003) was able to rule out the possibility of perceptual deficits in negative priming using a localization task. Compared to controls, the schizophrenic group showed reduced negative priming. This finding was interpreted as indicating that inhibition in schizophrenia might be more diffuse than in identification tasks. Studies of negative priming in Obsessive Compulsive Disorder (OCD) or anxiety disorders (McNally et al., 2001) yielded mixed results depending task parameters (e.g., types of task, stimulus presentation time, interval between response to the prime trial and the onset of probe trial) and/or subgroups (checkers vs. non-checkers). As in studies on schizophrenia, there are alternative accounts for deficits in OCD including sensory input gating and saccadic eye movement (Hoenig, Hocherein, Müller, & Wagner, 2002). Negative priming studies of ADHD (see 2.3.3 for a detailed review) yielded mixed results.

Summary

In sum, negative priming paradigm has been used to examine inhibitory aspects of selective attention in different populations. Most studies using the negative priming paradigm yielded inconsistent results depending on task parameters and subgroups within the same population. Given that different populations can show similar deficits in negative priming, it seems important to use multiple tasks along with a design in which specific task parameters can be examined separately in order to understand underlying mechanism in different populations. In the following section, factors that can affect the patterns in negative priming will be reviewed with a focus on temporal pattern of negative priming.

2.3.2 Time course of negative priming

The magnitude of negative priming can be affected by many variables (Neill et al., 1995). As for a time course, development and persistence are two important parameters. Studies have demonstrated that negative priming requires time to develop. That is, the inhibitory mechanism underlying the negative priming effect takes time to build from the onset of a distracting stimulus. One line of research investigated negative priming as a function of stimulus-onset asynchrony (SOA; i.e., the time between the onset of the prime stimuli and the onset of the probe). Lowe (1985) measured negative priming effects on the Stroop task at SOAs of 50, 100, 200, and 400ms. The data showed that significant negative priming occurred at all SOAs except the shortest (50ms). He ruled out the possibility of a failure to process the prime by showing positive priming from the prime target color at 50-ms SOA (e.g., the word *green* in red ink following the word *blue* in red ink yielded facilitation relative to unrelated stimuli). Yee (1991) found significant positive priming at the 500-ms SOA, but negative priming at the 600-ms SOA in the lexical decision task, indicating that the development of negative priming may occur between 500 and 600ms after the onset of the prime stimuli.

Another line of research investigated negative priming under speed versus accuracy criteria. Studies reported negative priming under an accuracy criterion, but positive priming under a speed criterion (Neill & Westberry, 1987; Neumann & DeSchepper, 1992). These findings were interpreted as reflecting the time course of development in the prime trial. That is, when following instructions emphasizing speed, the subject may respond before the highly-activated distractor information has been completely suppressed, resulting in positive priming for the corresponding probe. In contrast, when following strict accuracy instructions, distractor information may be more completely suppressed before the subject responds, yielding negative priming on the probe trial.

A second important variable is the duration of the effect following a selection response. In their study of the time course of negative priming, Hasher et al. (1996) compared studies that reported relatively stable negative priming effects with those that reported a sharp decline. They found that "response-to-stimulus" delay intervals (RSIs; the interval between response to prime trials and the onset of probe trials) and presentation time are two important parameters. More specifically, relatively stable negative priming effects were reported in studies that used a between-subjects (or between-blocks) manipulation and/or brief (150-300ms) experimenter-controlled presentations of the stimulus display. In contrast, a sharp decline was reported in studies that used a within-subjects random sequence of RSIs and/or longer exposure to the stimulus (i.e., the stimulus remained on the screen until the subject responded).

In an attempt to investigate differential deficits in inhibitory functioning in schizophrenia and OCD, Hoenig et al., (2002) used the negative priming paradigm in which RSIs were varied and effects of distractor features (identity and location) on negative priming were examined separately. Analogous to the spatial localization task used by Tipper et al. (1995), subjects were asked to select a larger one of two cardinal numbers presented under four different conditions: 1) the stimulus on the control trial neither match the identity nor the location of the target and the distractor on the previous trial, 2) the target stimulus on the location priming trial matched that of the distractor on the previous trial, 3) the target stimulus on the identity priming matched the identity of the distractor on the previous trial, 4) the target stimulus on both location and identity priming shared both location and identity of previous distractor. The study found that schizophrenic patients compared to both OCD patients and normal controls showed reduced location negative priming. Subgroup analysis of the OCD group revealed that checkers showed reduced

negative priming at 500ms RSI, but enhanced negative priming at 2000ms RSI whereas non-checkers showed intact negative priming at 500ms RSI, but reduced negative priming at 2000ms RSI. This study has implications for the importance of taking into account a time course as well as examining task parameters separately when investigating negative priming effects across different clinical populations.

Summary

In sum, tracking the time course of negative priming poses a challenge due to multiple factors that can affect the magnitude, development, and persistence of negative priming. It should be noted, however, that investigating negative priming effects at one point in time with a focus on the magnitude can lead to a misunderstanding of the effects. In addition, using multiple negative priming tasks and/ or a design in which multiple task parameters can be examined separately can seems important to adequately differentiate negative priming effects in different clinical populations.

2.3.3 Negative priming in ADHD: Empirical findings

Studies of negative priming in both children and adults with ADHD yielded mixed results. Nine studies were identified using a negative priming paradigm in ADHD, six of which were with children and three of which were with adults. Findings in these studies will be reviewed based on task types including naming, categorization, matching, and localization tasks as described in section 2.3.1. Naming tasks especially, the Stroop test were the most common, comprising five studies (McLaren, 1989; Mclaughlin, 2002; Nigg et al., 2002; Ossmann and Mulligan, 2003; Visser, Das-Smaal, & Kwakman, 1996). Those studies were only partially supportive of an inhibitory deficit in

ADHD. Two studies (Ozonoff & Strayer, 1998; Marriott, 1998) using the letter-matching task reported significant differences in negative priming between the ADHD group and normal controls, but a study using a shape matching task (Armstrong, Hayes, & Martin, 2001) did not find significant differences between the two groups. One study using a categorization task (lexical decision; Armstrong et al., 2001) reported a trend for an inhibitory deficit in ADHD. As for the localization task, one study (Marriott, 1998) reported a significant group difference.

Studies using naming tasks

The first study that applied a negative priming paradigm to ADHD, found that children with ADHD, compared to normal children, failed to show a negative priming effect on the card version of the Stroop test (McLaren, 1989). Given potential problems with the card version of the test (see 2.2.1 for a detailed discussion), however, the discussion will focus on studies that used the single trial version. Two studies that used the single trial version of the Stroop test fail to find the reduced negative priming effects in children (Mclaughlin, 2002) or adults (Nigg et al., 2002). It should be noted, however, that one study (Visser et al., 1996) found a significant difference in children who scored high versus low on social impulsivity and the other study found a significant difference between adults with ADHD and controls although this study used a different color-naming task (Ossmann and Mulligan, 2003).

Nigg et al. (2002) compared the neuropsychological performance of college students with ADHD/C (n = 22) to that of normal controls (n = 21) on the anti-saccade and negative priming tasks. They hypothesized that adults with ADHD would have deficits in the suppression of the reflexive response to a cue as measured by anti-saccade errors and the suppression of the extraneous response during a waiting period as measured by anti-saccade anticipations. On

the contrary, they predicted no deficits in suppressing information as measured by negative priming. The data supported their hypotheses, indicating that deficits in motor suppression might be integral to ADHD, whereas cognitive inhibition might not be. Using a similar design to Nigg's (2002) study, Mclaughlin (2002) found no significant group difference between children with ADHD and non-disordered children. It should be noted, however, that the combination of long exposure to stimuli (i.e. stimuli remained on the screen until a response) and 800ms RSI might have lead to a failure to detect sharp decline in negative priming effects (see 2.3.2 for factors that affect the magnitude of negative priming). Further, as discussed in the previous section, investigating negative priming effects at one point in time with a focus on the magnitude can lead to a misunderstanding of the effects. Drawing conclusions based on one negative priming task can be over-generalizing.

Contrary to these studies that found no differences between ADHD and normal controls, there were two studies that reported significant group differences by using a naming task but with different task parameters. First, in an attempt to differentiate types of impulsivity, Visser et al. (1996) used the single trial version of the negatively primed Stroop test in children who were rated for cognitive and social impulsivity by teachers. As measured by Visser Impulsivity Scale, social impulsivity was referred to as hyperactivity (e.g., talking before their turn, reacting to things that happen in a classroom) and cognitive impulsivity as impulsive working style (not analyzing their work before starting it, not listening to instructions). Unlike the Stroop task used in the Nigg et al. (2002) and Mclaughlin (2002) studies, trials in this study were presented as an unbroken list instead of in pairs. The results showed that children who scored high on social impulsivity showed reduced negative priming compared to children who were low (71ms for the high social impulsivity group and 121ms for the low social impulsivity group) whereas

there was no difference between children who scored high or low on cognitive impulsivity (113ms for the high group and 106ms for the low group). Further, there was no significant group difference in interference effect. There was a trend for the high-cognitive impulsive type to be slower than the low group. These findings were interpreted as an indication that the negative priming might be a better measure for cognitive inhibition and is separate from interference. These findings seem to have some implications for subtype differences in ADHD. Although children in this study were not assessed for ADHD, cognitive impulsivity might be related to inattentive symptoms and social impulsivity to hyperactive/impulsive symptoms in DSM-IV. Following this line of reasoning, it would be interesting to see if the ADHD/IA type (purportedly high only on cognitive impulsivity) would not show reduced negative priming compared to the ADHD/HI or ADHD/C types.

In another naming study, Ossmann and Mulligan (2003) compared the performance of college students with ADHD to that of their peers on the negative priming task using Kane's paradigm in order to test the inhibitory account of ADHD. In this paradigm, stimuli were presented for fixed 300ms followed by a pattern mask for 100ms. The response time was also fixed for 1500ms. RSI might have varied for groups depending on their response times (the mean RSI for the ADHD group 1200ms; the mean RSI for the control group 1224ms). The control group showed a significant negative priming effect (12.0ms) while the ADHD group failed to show a negative priming effect (.10ms). The magnitude of negative priming in the control group was comparable to the magnitude in other studies using the same paradigm (Hasher et al., 1991; Kane et al., 1997). It should be noted, however, that the inclusion criteria for the ADHD group only required participants to document the previous diagnosis by mental health professionals and experimenters did not screen those participants further. In addition, information about subtypes was

not provided in the study. Thus, results might reflect negative priming effects in both ADHD subtypes.

Studies using other negative priming tasks

Using the letter-matching task, Ozonoff and Strayer (1998) found reduced negative priming in children with ADHD comorbid with either Tourettes syndrome (TS) or OCD compared to TS only and normal controls (6.7 ms for the ADHD+TS/OCD group; 15.3ms for TS only; 19.7ms for controls). Armstrong et al. (2001) found no significant group difference using a shape-matching task.

Another demonstration of an inhibitory deficit came from the finding that children with ADHD showed a significantly reduced negative priming effect on the letter-matching task and the localization task (Marriott, 1998). The study consisted of two experiments, one with children recruited from the community, and the other with children from a clinic setting. Children between 8 and 10 years old were classified into two groups using Hyperactivity Index T-scores on the Conners Parent and Teacher Rating Scales (Conners, 1969, 1970). Results showed that hyperactive boys, relative to age-matched non-hyperactive boys, produced significantly smaller negative priming effects, indicating that hyperactive boys did not inhibit mental representation of distracting stimuli to the same degree as their non-hyperactive peers. It should be noted, however, that the screening process was based on rating scales, making it difficult to compare study findings with those using DSM-IV criteria.

Finally, Gaultney et al. (1999) used the negative-priming Stroop and directed-forgetting tasks to investigate the efficiency of cognitive inhibition in children with ADHD. Contrary to their hypotheses, the data suggested that children with ADHD, relative to normal children, did not show performance deficits in these measures. The failure in detecting group differences may be

due to a wide range in the participants' ages (they were between 8 and 15 years old). Consolidating the data of pre-teen participants with that of adolescents might have canceled out the inhibitory effects for each group. Further, trials were presented in a block format. This might be particularly problematic for the negative priming condition because subjects could have used the strategy of looking at the following item for each trial and ignoring the current item. As Ossmann and Mulligan (2003) pointed out, this format might also tap episodic retrieval process rather than inhibitory processes.

Summary

In sum, negative priming studies in ADHD showed inconsistent result. On a cross task level, one explanation for the discrepancy might be related to differences in tasks that were used. Different types of tasks might tap different processes, and thus drawing conclusions based on one task may be unwarranted. Another possible explanation for discrepant findings may be related to task parameters (e.g., duration of stimulus display, RSI, etc.). None of the negative priming studies of ADHD reviewed here examined these task parameters separately. As reviewed in the negative priming studies on other clinical populations, investigating specific task parameters along with the use of multiple negative priming tasks can be of particular importance in differentiating inhibitory processes that underlie different clinical symptom profiles. Due to the lack of research on negative priming in subtypes of ADHD, in the subsequent section reviews negative priming studies on personality as a context for gaining insights into subtype differences in ADHD.

2.3.4 Negative priming and personality: implications for subtypes

Two constructs that have been related to negative priming and are of potential relevance to the inattentive symptoms of ADHD are cognitive failure and absorption (i.e., a tendency to immerse in sensory and imaginative experiences), as measured by the Cognitive Failures Questionnaire (CFQ; Broadbent et al., 1982) and the Tellegen Absorption Scale (TAS; Tellegen & Atkinson, 1974), respectively. The CFQ is a self-report measure of failures in perception, memory, and motor function. Subjects estimate the frequency from "Never" to "Very Often," of various lapses, including questions like, "Do you read something and find that you haven't been thinking about it and must read it again?" "Do you fail to notice signposts on the road?" and "Do you find you forget people's names?" The TAS is a self-report questionnaire that measures the degree to which one becomes "absorbed" in certain experiences to the exclusion of others. It consists of statements like, "When I listen to music, I can get so caught up in it that I don't notice anything else (TRUE/FALSE)."

The first study on the relationship between cognitive failure and negative priming (Tipper & Bayilis, 1987) found that significant negative priming occurred only in low-CFQ subjects, whereas a non-significant trend toward positive priming in high-CFQ subjects suggested that cognitive lapses may be due to an inadequate inhibition of distracting information.

The second on the relationship between absorption and negative priming found a large negative priming effect in the Stroop task for high absorbers, relative to low absorbers. The authors suggested that high absorbers suppressed an ignored subject so thoroughly that it took them longer to switch their attention. In the final study, Neill et al. (1990) used both the TAS and the CFQ and found that, contrary to their predictions, there was a modest but significant positive relationship ($r = .33$, $p < .01$) between the two variables. This indicated that cognitive lapses might be due to the over-inhibition of ongoing

experiences as well as the under-inhibition of distracting information, both of which reflect an inefficient/ deficient inhibitory mechanism.

When this information is applied to ADHD research, the relationship between cognitive lapse and absorption suggests several viable predictions about subtype differences. First, given that children with ADHD are often described with phrases like “forgetful” and “does not seem to listen”, it makes intuitive sense that both the ADHD/C and ADHD/IA subtypes would be associated with high scores on the CFQ. Second, the fact that children with ADHD/IA are often characterized as “daydreamy” might indicate that they would score high on the TAS. And finally, given the inverse relationship between cognitive lapse and absorption, one can expect that the two ADHD subtypes might exhibit opposite performance patterns on cognitive inhibition as measured by the negative-priming task. That is, the ADHD/C type would be expected to exhibit a smaller negative-priming effect than the normal control group, whereas the ADHD/IA type would be expected to show a greater negative effect than the normal control group.

Chapter 3

Experiment

3.1 Rationale for the current study

Recent reviews have suggested that the ADHD subtypes show different types of attentional deficits. That is, at a behavioral level, children with ADHD/C have been described as irresponsible, sloppy, impulsive, distractible, and likely to answer without thinking. In contrast, the ADHD/IA group is characterized as daydreamy, spaced out, being easily confused, and passive (Carlson, Shin, and Booth, 1999). It has been suggested that these patterns may reflect both descriptive and etiological differences in the nature of inattention displayed by the ADHD/C and ADHD/IA subtypes (Carlson & Mann, 2002).

Given that the ADHD/C and ADHD/IA types only share inattentive symptoms according to DSM-IV, understanding the nature of inattention in ADHD might be of particular importance in differentiating these subtypes (Nigg, 2001). According to Barkley's theory of ADHD (1997), the combined ADHD type (ADHD/C) has deficits in behavioral rather than cognitive inhibition and inattentive symptoms in this subtype are secondary to behavioral inhibition. In contrast, he suggested the core deficit in the ADHD/IA type relates to selective attention, which is separate from behavioral inhibition, but related to cognitive inhibition. In contrast to this notion, Nigg (2001) argued that the association between the ADHD/C and deficits in cognitive inhibition

remains unclear. As for subtypes of ADHD, Nigg suggested the use of a more specific measure for investigating cognitive inhibition in the ADHD/C as well as ADHD/IA types.

In an attempt to incorporate functional and structural anomalies into specific neuro-cognitive deficits, most of ADHD theories were based on studies that used neuroimaging techniques and neuro-cognitive tasks considered to tap a variety of brain functions. It should be noted, however, that the constructs were often ill-defined and that the same constructs were often used differently by different researchers (e.g., executive function, response inhibition, selective attention, etc.). Further, even with the advent of modern brain imaging technologies, the complexity of brain networks (cortical-cortical and cortical-subcortical) still poses a challenge to research on neurological correlates of psychiatric conditions in general, and ADHD in particular. In addition, the validity of putative neuropsychological tasks and the sensitivity/ specificity of these tasks are far from well-established. Neuro-cognitive studies of subtype differences in ADHD failed to differentiate the ADHD/IA type from the ADHD/C subtype although both subtypes showed different profiles from non-diagnosed controls. Thus, it seems important to find laboratory tasks that can differentiate ADHD subtypes while addressing the limitations of putative measures.

Drawing from clinical, personality, and cognitive psychology literature, this study is based on the assumption that both ADHD/C and ADHD/IA types might have an inefficient inhibitory mechanism, though different processes may underlie their inefficient inhibitory mechanism. That is, deficient inhibition in ADHD/C might stem from under-active cognitive inhibition whereas that in ADHD/IA might be related to overactive cognitive inhibition.

To test this hypothesis, this study used a negative priming paradigm as a measure of the magnitude of cognitive inhibitory processes. The time course of

negative priming was also tracked in order to capture the build-up and the decay of inhibitory processes. Two negative priming tasks were developed based on Neill's matching paradigm for the letter task (1990) and Tipper's paradigm (1995) for the localization task to investigate if profiles of negative priming in these tasks would be the same or different for the two ADHD subtypes. Each task was administered to college students with ADHD/C or ADHD/IA, and normal controls at two RSI conditions: 500ms and 1000ms.

The negative priming paradigm has been extensively studied for investigating inhibitory aspects of selective attention, although other cognitive processes (e.g., retrieval) can also be related to negative priming effects. Negative priming studies in ADHD have yielded inconsistent results, some suggesting reduced negative priming in ADHD whereas others suggesting intact negative priming. Unlike negative priming studies in other psychiatric populations, none of the ADHD studies examined specific task parameters (e.g. RSI, dstractor features, and the use of feedback/reward), which might affect the magnitude of negative priming effects. Further, these studies have not examined negative priming among the ADHD/IA type. Given that other psychiatric populations (e.g., schizophrenia, anxiety, and depression) showed similar deficits to those of ADHD, tracking the time course using two different tasks might be important not only to understand potential differences between ADHD subtypes but also to differentiate deficits associated with ADHD from other psychiatric conditions.

The time course of facilitation using the same tasks was also examined to understand better selective attention in both subtypes. If a selective attention deficit is at the core of inattentive symptoms in the ADHD/IA type (Barkley, 1997), then the group would show different profiles of both negative priming and facilitation from non-diagnosed controls. On the contrary, the ADHD/C type might not show different profiles of facilitation from the non-diagnosed

controls while showing different profiles of negative priming from the control group.

In sum, the main purpose of the current study was to test whether the ADHD/C, ADHD/IA, and normal control groups show different patterns of negative priming as a function of RSI. Studies that applied a negative priming paradigm to ADHD have yielded inconsistent results. Discrepancies in findings might be related to differences in task parameters. Further, these studies have drawn conclusions about inhibitory processes based on one negative priming task (mostly naming tasks) and did not include ADHD/IA group, limiting findings to only the ADHD/C group. The current study also included the facilitation condition to study the time course of the excitatory/facilitatory aspect of selective attention. Specific hypotheses are put forth at the beginning of each analysis in the results section (**3.3**).

3.2 Method

3.2.1 Participants

A total of 44 college students between 18 and 24 years old were assigned to one of three groups: (1) those who met the criteria for ADHD/C, (2) those who met the criteria for ADHD/IA, and (3) non-diagnosed controls (NC). Participants were assigned to the ADHD/C group if they (1) had previously been diagnosed with ADHD by a psychologist or psychiatrist, and (2) had at least 6 inattentive symptoms (for the ADHD/IA group) or at least 6 inattentive symptoms and 6 hyperactive/impulsive symptoms (for the ADHD/C group) that were present in childhood. This was assessed using DSM-IV criteria during an initial telephone-screening interview. A total of 28 participants were identified with ADHD, 17 for the ADHD/C group and 11 for the ADHD/IA group. Given

the high rates of comorbidity, students with ADHD comorbid with a history of oppositional defiant disorder (ODD) and conduct disorder (CD) were also included. Eleven participants with ADHD/C met criteria for ODD (64.7%) and five met criteria for CD (29.4%). Three participants with ADHD/IA met criteria for ODD (27.3%) and one met for CD (9%).

Participants with ADHD were recruited from The University of Texas at Austin through advertisements at campus offices [e.g., the Office of Services for Students with Disabilities (SSD) and the UT Counseling and Mental Health Center (CMHC)], flyers posted at campus kiosks and public bulletin boards, and announcements in large classes and student organization meetings. Originally, an additional source was to include Austin Community College (ACC) in order to make the ADHD sample more representative, but only three participants from ACC participated. Participants in the NC group (n = 16) were recruited by word of mouth referral (i.e., friend recruitment) or flyers.

Due to the overwhelmingly male-biased gender ratio (4:1 to 10:1 in clinical samples), limited resources for this research, and low likelihood of getting sufficient female participants for meaningful comparison purposes, enrollment in the study was limited to males. The mean age of participants was 20.8 years (SD = 1.6). The mean IQ was in the average range (M = 104.9; SD = 9.9), but the mean WRAT-III reading was in the above average range (M = 112.9; SD = 5.6). Groups did not differ in age or IQ, but the NC group scored significantly higher on the WRAT-III than did the ADHD/C group (Scheffe test, p = .04.). Race and ethnicity were as follows: 34 (77.3%) Caucasian; 7 (15.9%) Asian; 2 (4.5%) Latino/Hispanic; 1 (2.3%) African-American. A chi-square test for independence was conducted to determine if the distribution of ethnicities was significantly different for the three groups. Due to the limited number of participants for each ethnic group, non-Caucasian ethnicities were collapsed into one category. The Chi-square test revealed a marginally

significant difference in the distribution of ethnicities across the three groups, $\chi^2 = 4.86$, $p < .10$. Demographic characteristics for groups are summarized in Table 1 along with descriptive measures.

Table 3.1 Descriptive Characteristics of Groups

Variable	ADHD/C (n = 17) M (SD)	ADHD/IA (n = 11) M (SD)	NC (n = 15) M (SD)
Age (years)	20.8 (1.6)	20.9 (1.9)	20.7 (1.5)
IQ	104.1 (10.0)	108.5 (6.9)	102.9 (11.7)
WRAT-III	110.4 (5.7) [a]	112.4 (5.8)	115.9 (4.3)
BDI	5.0 (4.5)	7.3 (8.2)	3.4 (3.7)
BAI	11.3 (9.1)	12.9 (12.5)	6.6 (6.7)
WURS	47.6 (17.5) [a]	40.8 (11.6) [c]	15.7 (14.7)
CAARS-S:SV			
A (Inattention)	75.9 (12.5) [a]	78.2 (10.1) [c]	45.0 (7.5)
B (H/I)	74.3 (12.4) [a,b]	53.8 (11.1) [c]	45.2 (6.9)
C (total)	77.8 (12.1) [a,b]	67.1 (7.9) [c]	44.5 (6.9)
D (index)	60.5 (8.6) [a]	57.0 (5.4) [c]	41.2 (6.6)
IRS	106.7 (19.8) [a]	106.6 (15.5) [c]	77.4 (18.4)
CFQ	54.4 (9.5) [a]	57.0 (10.4) [c]	35.4 (13.6)

Note. BDI = Beck Depression Inventory-Short version; BAI =Beck Anxiety Inventory; WRAT-III = Wide Range Achievement Test-III; WURS = Wender Utah Rating Scale-abbreviated version; CARRS = Conners Adult ADHD Rating Scale-Self Report: Screening Version; H/I = Hyperactivity-Impulsivity IRS = Internal Restlessness Scale; CFQ = Cognitive Failure Questionnaire; ADHD/C=attention deficit hyperactivity disorder/the combined subtype; ADHD/IA=attention deficit hyperactivity disorder/the predominantly inattentive subtype; NC=non-diagnosed controls; *a* = ADHD/C vs. NC, *b* = ADHD/C vs. ADHD/IA, *c* = ADHD/IA vs. NC, all $p < .05$

3.2.2 Screening Measures

The Adult Interview for ADHD (Barkley, 1998)

The interview covers child and adulthood ADHD symptoms based on the DSM-IV as well as specific areas of impairment related to these symptoms. Further, the interview probes for the presence of commonly comorbid conditions, including ODD and CD.

Information and Picture Completion Subscales of the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1984)

This brief form is considered to be a valid method of estimating Full Scale IQ (average correlation with Full Scale of .88 for the standardized sample). Based on scores on this dyad, estimated IQ was derived using Kaufman's formula (1990).

Reading subtest of the Wide Range Achievement Test-III (WRAT-III; Wilkinson, 1993)

When used in conjunction with the WAIS-R, which has the same standard deviation units, the WRAT-III is considered to be a valuable screening tool for Learning Disability.

3.2.3 Descriptive Measures

Wender Utah Rating Scale-abbreviated version (WURS; Ward, Wender, & Reimherr, 1993)

The original WURS is a 61-item self-report measure on adults' recollections of childhood ADHD symptoms. Items are rated on a 5-point scale from 0 (*not at all*) to 4 (*very much*). An abbreviated version consists of 25 items that were found to be an efficient means of differentiating individuals with ADHD from those without it. A raw score cutoff of 46 on this 25-item subset is recommended to identify participants with ADHD; this score yields a sensitivity of 86% and a specificity of 99%. The Spearman-Brown corrected split-half reliability was r = 0.9 (in non-ADHD adults, N = 100). The Pearson correlation coefficients, determined for concurrent validity with the Parent Rating Scale scores (Conners, 1973), were $r = 0.49$ for non-diagnosed controls and $r = 0.41$ for adults with ADHD.

Conners Adult ADHD Rating Scale-Self Report: Screening Version (CAARS-S:SV; Conners, Erhardt, & Sparrow, 1999)

The CAARS-S: SV is a 30-item self-report measure designed to probe current manifestations of ADHD in adults. Eighteen items are worded closely to the

DSM-IV criteria for ADHD; twelve items (ADHD index) are included to provide additional behavioral information related to adult ADHD. Items are rated on a 4-point scale from 0 (*not at all or never*) to 3 (*very much or very frequently*). This form yields two factor scores, one for DSM-IV Inattentive Symptoms and the other for DSM-IV Hyperactive-Impulsive Symptoms (.81 and .64 1-month test-retest reliabilities, respectively). The Inattentive and Hyperactive-Impulsive scales have high positive correlations with matching DSM-IV symptom clusters (.89 and .74, respectively) in males (Conners et al., 1999).

Internal Restlessness Scale (IRS; Iwaszuk et al, 1997)

IRS is a 24 item self-report measure developed to examine if hyperactivity in children with ADHD is replaced by mental or internal restlessness in adults with ADHD. Three items are scored in a reverse direction: " I am organized," "I feel mentally calm," and "I focus on tasks." Items are rated on a 7- point scale from 0 (*none of the time*) to 7 (*all of the time*). In one study of college students (Weyandt, Iwaszuk, Fulton, Ollerton, Beatty, Fouts, Schepman, & Greenlaw, 2003), the ADHD group (M = 112.25; SD = 23.79) scored significantly higher on this scale than the control group (M = 76.00; SD = 27.95). The test-retest reliability over 4 week period for the ADHD group was .80 ($p < .01$) and was correlated significantly with Adult Rating Scale (ARS, Weyandt, et al., 1995; r = .62, $p < .01$). This scale yielded four factors including cognitive distractibility, mental restlessness, cognitive impulsivity, and disorganization.

Beck Depression Inventory-short form (BDI-SF; Beck & Beck, 1972)

The short version of the BDI consists of 13 items, each of which is rated on a 4-point scale and summed. Higher scores indicate more severe depression. The BDI has good internal consistency (alpha = .81) and has been widely used as a brief screening measure for depressive symptomatology.

Beck Anxiety Inventory (BAI; Beck & Steer, 1990)

The BAI is a 21-item self-report measure that taps symptoms of anxiety. This measure has been shown to distinguish effectively between clinically depressed and anxious populations. Responses for each item are on a 4-point scale. The BAI is widely used and has good internal and test-retest reliability as well as established validity.

Cognitive Failure Questionnaire (CFQ; Broadbent, Cooper, Fitzgerald, & Parkes, 1982)

The CFQ is a 25-item self-report measure of failures in perception, memory, and motor function. Subjects estimate the frequency from 0 (*Never*) to 4 (*Very OFacilitationen*) of various lapses, including questions like, "Do you read something and find that you haven't been thinking about it and must read it again?" "Do you fail to notice signposts on the road?" and "Do you find you forget people's names?" The score is considered to be stable over long periods (.82 and .80 test-retest reliability over 21 weeks and 65 weeks, respectively).

Table 3.2. Correlation matrix for descriptive measures of attention

Variable	1	2	3	4	5	6	7
1. WURS	1.00	.70	.80	.80	.82	.67	.69
2. CARRS.A		1.00	.66	.92	.87	.67	.75
3. CARRS.B			1.00	.89	.80	.55	.56
4. CARRS.C				1.00	.89	.66	.70
5. CARRS.D					1.00	.72	.77
6. IRS						1.00	.69
7. CFQ							1.00

Note. WURS = Wender Utah Rating Scale-abbreviated version; CARRS = Conners Adult ADHD Rating Scale-Self Report: Screening Version; Hyperactivity-Impulsivity IRS = Internal Restlessness Scale; CFQ = Cognitive Failure Questionnaire

3.2.4 Experimental Measures

Letter matching task

Apparatus and stimuli. The task was modified from the one used in Neill et al. study (1990). Stimuli were presented on a Macintosh computer using SuperLab software. The computer recorded response accuracy and RTs with a millisecond accuracy for the key press response. Stimuli consisted of the following six uppercase letters: C, D, H, K, S, and T, which were presented in a five-letter string (e.g., CDCDC). In each string, the first, third, and fifth flanker letters were identical (e.g., C). The second and fourth target letters were always different from the flanker letters. The video screen image of each letter was 4mm wide and 6 mm high. When viewed from a distance of 57 cm, the space between adjacent letters were 0.3 degrees, and the edge-to-edge width of a five-letter group was 3.8 degrees.

Procedure. Participants were instructed to press the "S" key indicating "same" if the two target letters were the same as each other and to press the "D" key indicating "different" if those two letters were different. On half of the trials the target letters were the same (e.g., CDCDC), while on the other half of the trials the target letters were different (e.g., CDCHC). Speed as well as accuracy of responding were equally emphasized.

Design. All the trials were presented in a pair that consisted of the prime and the probe. The experiment had a 3 (priming condition) × 2 (RSI) x 2 (preceding trial type) x 2 (current trial type) within-subject design. The first variable, priming condition, had three priming conditions: Control, Facilitation, and Negative Priming (NP). In the Control condition, neither the flanker nor the target letters in the prime appeared in the probe. In the Facilitation condition, target letters in the prime were repeated in the probe. In the NP condition, the flanker letter in the prime became one or both of the target letters in the probe

while the prime targets and probe flanker were unrelated. When the flanker letter in the prime comprised only one target letter in the probe the correct response would be “different” If the flanker letter in the prime comprised both target letters, then the correct response would be “same.”

The second variable was RSI: 500ms and 1000 ms.

The third and fourth variables were trial type (different or same). Preceding trial type has to do with responses on the prime and current trial type responses on the probe. These variables were included to see if the task in the current study was able to replicate major findings in the Neill et al. study on which the current task was based. This matching paradigm was originally used to examine whether or nor the particular target identities on the prime affect responses on the probe. It should be noted, however, that these variables were included more as a validity check for the task and thus, the focus of analyses will be on group differences and the effects of RSI on priming condition (i.e. time course).

The task began with a practice block of 6 negative priming, 6 control, and 12 facilitation trials. The remaining trials were organized into 4 blocks of 36 negative priming, 36 control, and 72 facilitation trials. The trials in each block were randomly presented. The sequence of events were as follows: 1) A pattern mask was displayed in the middle of the screen for 1000ms. 2) The prime display remained on the screen until the subject responded. 3) The blank screen was displayed for either 500ms in the 500ms RSI condition or 1000ms in the 1000ms RSI condition. 4) The probe display was presented. 5) The subject’s key stroke cleared the screen. 6) The next pattern mask appeared immediately.

The two RSI conditions were presented in a random sequence across blocks. All trials in which there was an error in responding to the prime and/or

probe displays were excluded from the response time data. Figure 1 illustrates a sample trial.

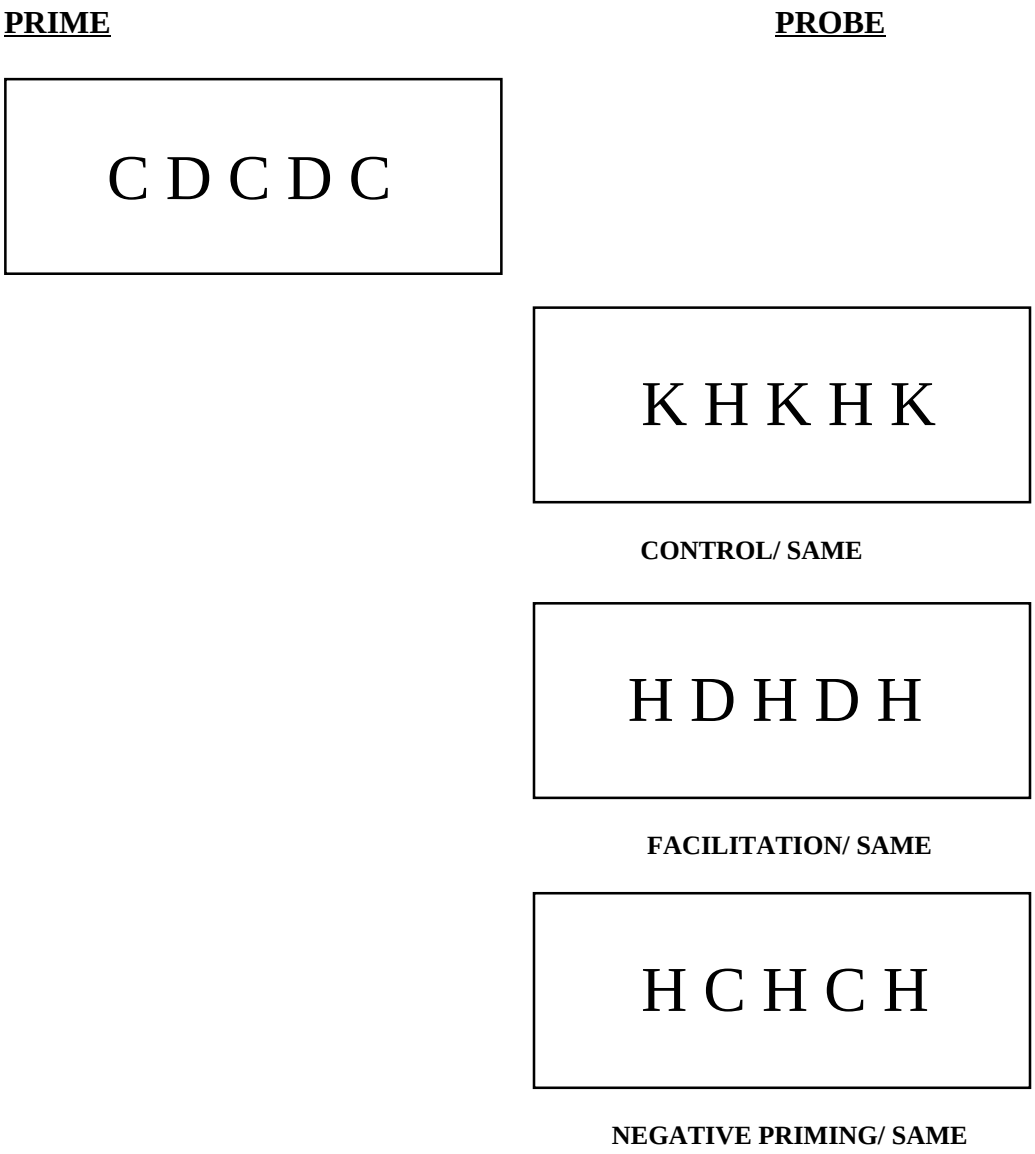

Figure 3.1: Illustration of the Letter-Matching Task. Examples of trials with different target letters: 1) Control-KHKSK, 2) Facilitation-HDHSH, & 3) Negative priming-HCHSH

Dependent variables included mean RTs and error rates for priming condition and RSI, facilitation scores indicated by differences in mean RTs between the Facilitation and Control conditions, and negative priming scores indicated by differences in mean RTs between the NP and Control conditions.

Localization Task

Apparatus and stimuli. The task was modified from the one used in the Tipper et al. study (1995). Stimuli were presented on a Macintosh computer using SuperLab software. The computer recorded response accuracy and RTs with a millisecond accuracy for the key press response. The following four uppercase letters were used as stimuli: C, D, H, and K. Three different sizes were used (see Figure 2). At a viewing distance of 57 cm, the heights of letters were as follows: 0.5° for Size 1, 1° for Size 2, and 1.5° for Size 3. Stimuli appeared in four possible locations: top, bottom, left, or right. A fixation cross was centered on the screen as a location marker.

Procedure. Participants were instructed to respond to the larger letter of two letters by pressing the key that corresponded to the location.

Design. All prime displays contained a Size 3 target letter and a Size 2 distractor letter. All probes contained a Size 2 target and a size 1 distractor.

The experiment had a 3 (priming condition) x 2 (RSI) × 2 (target identity) within-subject design. The first variable, priming condition had three levels: Control, Facilitation, and Negative Priming (NP). In the Control condition, the probe target and distractor both appeared in locations that were vacant during the prime. In the Facilitation condition, the probe target appeared in the same location as the preceding prime target, but the probe distractor appeared in a location that was previously unoccupied. In the NP condition, the probe target

appeared in the same location as the preceding prime distractor, but the probe distractor appeared in a location that was previously unoccupied.

The second variable was RSI. Two RSIs included 500 and 1000 ms.

The third variable was target identity. The identity of the probe target either matched or mismatched that of the prime distractor in the Control and NP conditions, but the identity of the probe target either matched or mismatched that of the prime target in the Facilitation condition. For example, consider a prime display in which the target and distractor are C and D, respectively. In the match condition, the target and distractor letters on the prime could be D and K, respectively (see Figure 2). This variable was included to examine if findings from the current study were comparable to those from the Tipper et al. study on which the current task was modified from. As in the latter matching task, this variable was not a focus on the study.

The task began with a practice block of 6 negative priming, 6 control, and 12 facilitation trials. The remaining trials were organized into 5 blocks of 24 negative priming, 24 control, and 48 facilitation trials. The trials in each block were randomly presented. The sequence of events were as follows: 1) A fixation cross were displayed in the middle of the screen for 1000ms. 2) The prime display remained on the screen until the subject responded. 3) The blank screen was displayed for either 500ms for 500ms RSI condition or 1000ms for 1000ms RSI condition. 4) The probe display was presented. 5) The subject's key stroke cleared the screen. 6) A fixation cross reappeared.

Dependent variables included mean RTs and error rates for priming conditions at each RSI. Facilitation scores indicated by differences in mean RTs between the Facilitation and Control conditions, and negative priming scores indicated by differences in mean RTs between the NP and Control conditions. Figure 2 illustrates a sample trial.

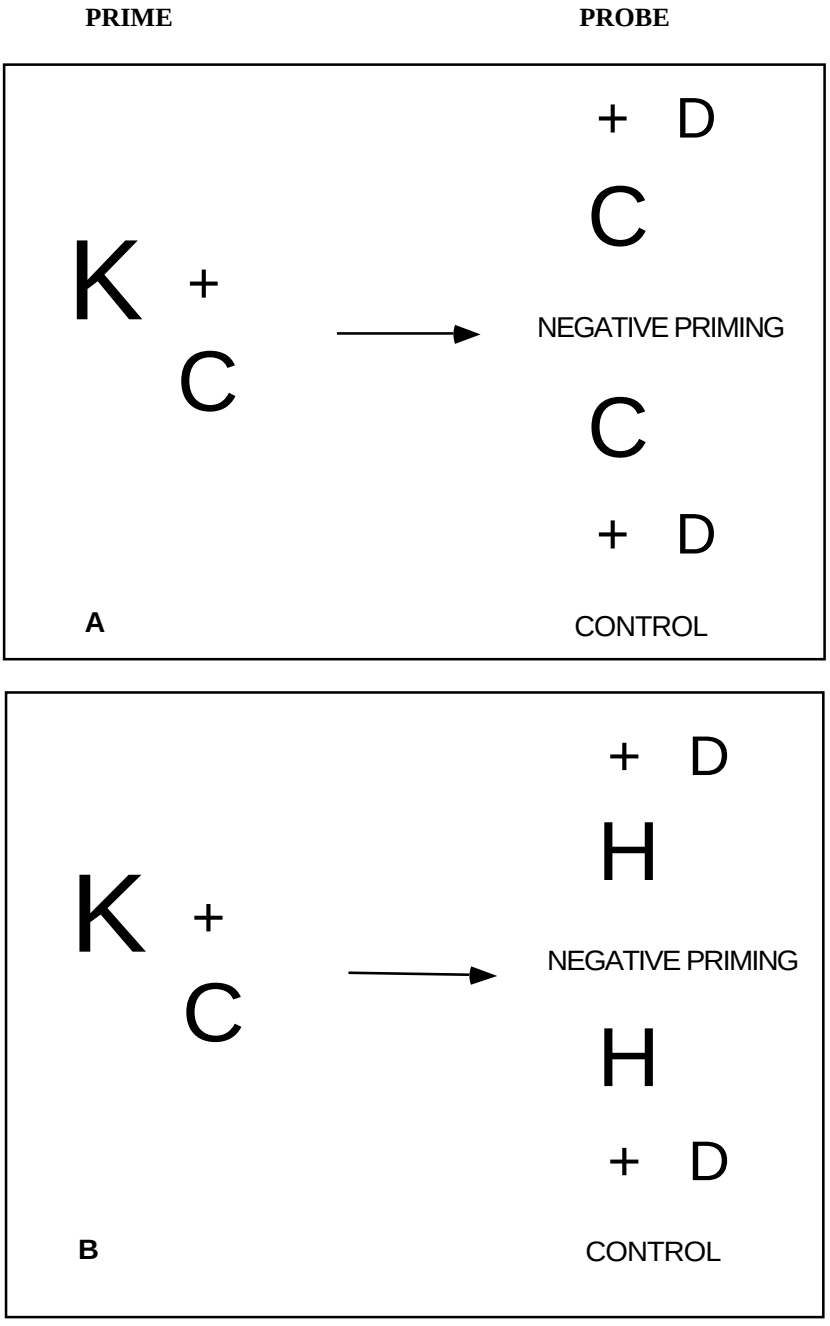

Figure 3.2: Illustration of the Localization Task. Panel A shows the match condition in which the identities of the prime distractor and probe target match; Panel B show the mismatch condition in which the identities mismatched.

3.2.5 Procedure

The Office of SSD and the UT CMHC distributed information regarding the study, an assistant posted flyers on campus, an investigator made announcements to classes and student organization meetings, and past participants informed their friends about the study. Potential subjects who contacted the investigator regarding participation were screened for ADHD symptoms using a semi-structured DSM-IV telephone interview. Eligibility for participation in the study procedures was determined by report of a prior ADHD diagnosis (from a psychologist, psychiatrist, or other mental health professional) and by student self-report of childhood ADHD symptoms, reaching a diagnostic cutoff for the ADHD/C or ADHD/IA types as determined by the DSM-IV criteria (or, in the case of NC participants, not meeting said criteria) at a screening interview. Nineteen (67.9%) out of 28 participants reported taking stimulant medication for ADHD symptoms at the time of interview. Participants who were taking stimulant medication were tested after 24 hours off medication.

At the outset of the data collection session, participants were given a brief description of the study procedure and asked to sign a consent form. Participants were instructed to fill out symptom measures, including BDI and BAI. They were then administered the subtests of the WAIS-R and the reading subtest of the WRAT-III, followed by the computer tasks. It took 4-5 sessions for participants to complete the study. Each session took approximately an hour. Participants were asked to fill out questionnaires the WURS, CARRS, CFQ, and IRS during breaks throughout the study. Thirteen of 17 participants with ADHD/C completed the study, three participants completed the letter-

matching task only, and one participant completed the localization task only. Nine of 11 participants with ADHD/IA completed the study, one participant completed the letter task only, and one participant completed the localization task only. Fifteen of 16 participants in the NC group completed the study and one participant completed the localization task only. Rates for completion of the study was highest in the order of the NC (93.8%), ADHD/IA (81.8%), and ADHD/C (76.5%) groups. Participants were paid $60 by the completion of the study.

3.3 Results

3.3.1 Final data set

Blocks in which error rates were above two and a half standard deviations (*SD*s) greater than the mean error rate for the sample, were discarded. The number of these blocks were tracked for each participant and used as part of a deviation index, which will be discussed in the following section. Trials in which RTs fell either below 200ms or 3*SD* above each subject's mean correct RTs in each RSI condition were considered to be errors and thus excluded. Only pairs in which an accurate response occurred in both the prime and the probe were included for analyses. Preliminary analyses of the data set indicated great variability both in RTs and *SD*s for both tasks. Mean RTs across all blocks with correct trials in the sample ranged from 428.0ms to 1352.1ms and *SD*s ranged from 58.3 to 564.3 in the letter matching task. Mean RTs was from 332.9ms to 915.3ms and that of *SD*s was from 46.7 to 523.7 in the localization task.

When determining what data to include, the investigator considered two competing priorities: 1) homogeneity of variance between groups to conduct

ANOVAS. 2) recognizing that response variability is a characteristic of pathology and thus excluding variability can jeopardize detecting group differences. With these considerations in mind, the final data set for each task was determined based on the following steps: 1) RTs on all trials were plotted across blocks for each subject to examine the quality of the data set. 2) Means and *SD*s of RTs on correct trials for each block were obtained for each participant. 3) Blocks in which RTs or *SD*s fell above 2*SD* of sample means were excluded from analyses. The number of blocks that were excluded was tracked for each subject and used as part of a deviation index, which will be discussed in the following section.

A comparison of scatter plots and the distribution of RTs and *SD*s for each participant with those for the entire sample led to the exclusion of some participants who showed an erratic pattern. Scatter plots of RTs in these participants showed numerous spikes instead of a narrow band of RTs as a function of time, suggesting that participants might have been disengaged from the task at hand much of the time (see **Figure 3.3** for examples of reliable versus unreliable data sets). In addition, these participants showed long RTs and/or large *SD*s (greater than 2*SD* of sample means) in most of the blocks whereas the rest of the sample rarely showed these patterns. Eight (6 ADHD/C; 1 ADHD/IA; 1 NC) out of 41 participants for the letter matching task were excluded and four (3 ADHD/C; 1 ADHD/IA) out of 40 participants for the localization task were excluded based on the steps described above. Four participants with ADHD (3 ADHD/C and 1 ADHD/IA) warranted exclusion for both the letter matching and localization tasks. Three participants showed an extreme pattern in the letter matching task, but not in the localization task. Given these two tasks might tap different processes, data sets for those participants were included for the localization task. Thus, a total of 33 participants were included for ANOVAs (10 ADHD/C, 9 ADHD/IA, & 14 NC)

for the letter matching task and a total of 36 participants (11 ADHD/C, 9 ADHD/IA, & 16 NC) for the localization task.

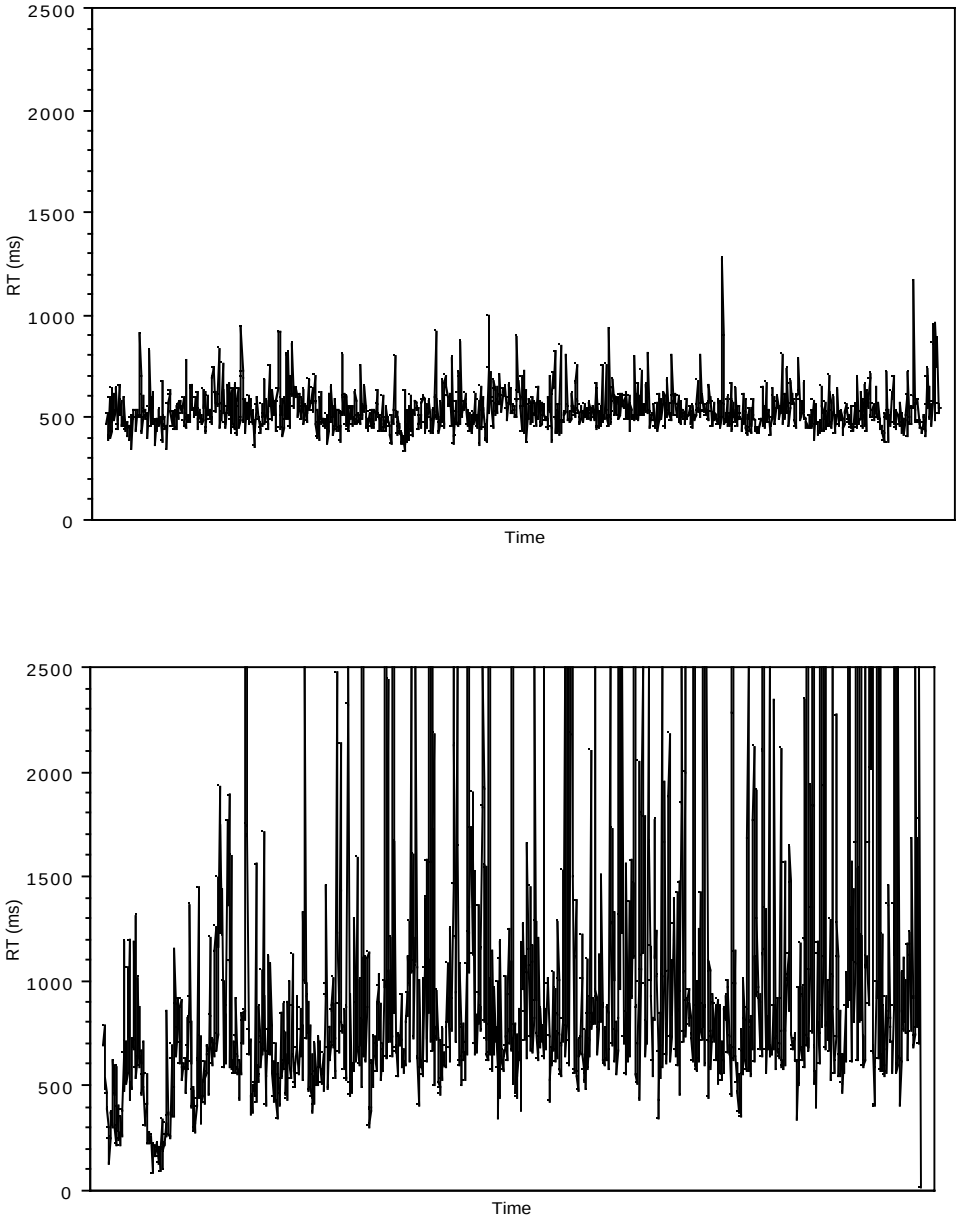

Figure 3. 3: Illustration of reliable versus unreliable data set. A data set of one participant in the NC group who showed a reliable pattern (Top); A data set of one participant with ADHD/C that was excluded (Bottom)

The assumption of homogeneity of variance between groups was assessed using an F-test. No DVs violated this assumption and the ratio of the largest to the smallest variance (Fmax) was within the acceptable range (less than 1 to 3, Keppel, 1991). The alpha level was set at .05.

3.3.2 Description of participants who were included vs. excluded:

As a validity check for the inclusion criteria, a deviation index was devised based on five criteria for each task including overall error rate with all blocks included, and mean, *SD*, skewness, and kurtosis of RTs on correct trials. **Figure 3.4** (top) illustrates mean deviation scores on these criteria. Another deviation index was devised based only on mean RT and *SD* in the final sample since these two were used as criteria to exclude blocks that were outliers (see 3.3.1). **Figure 3.4** (bottom) illustrates mean deviation scores on these criteria in the final sample. The bottom figure suggests that the final sample still captures some pathology associated with both ADHD groups even though some participants were excluded from analyses.

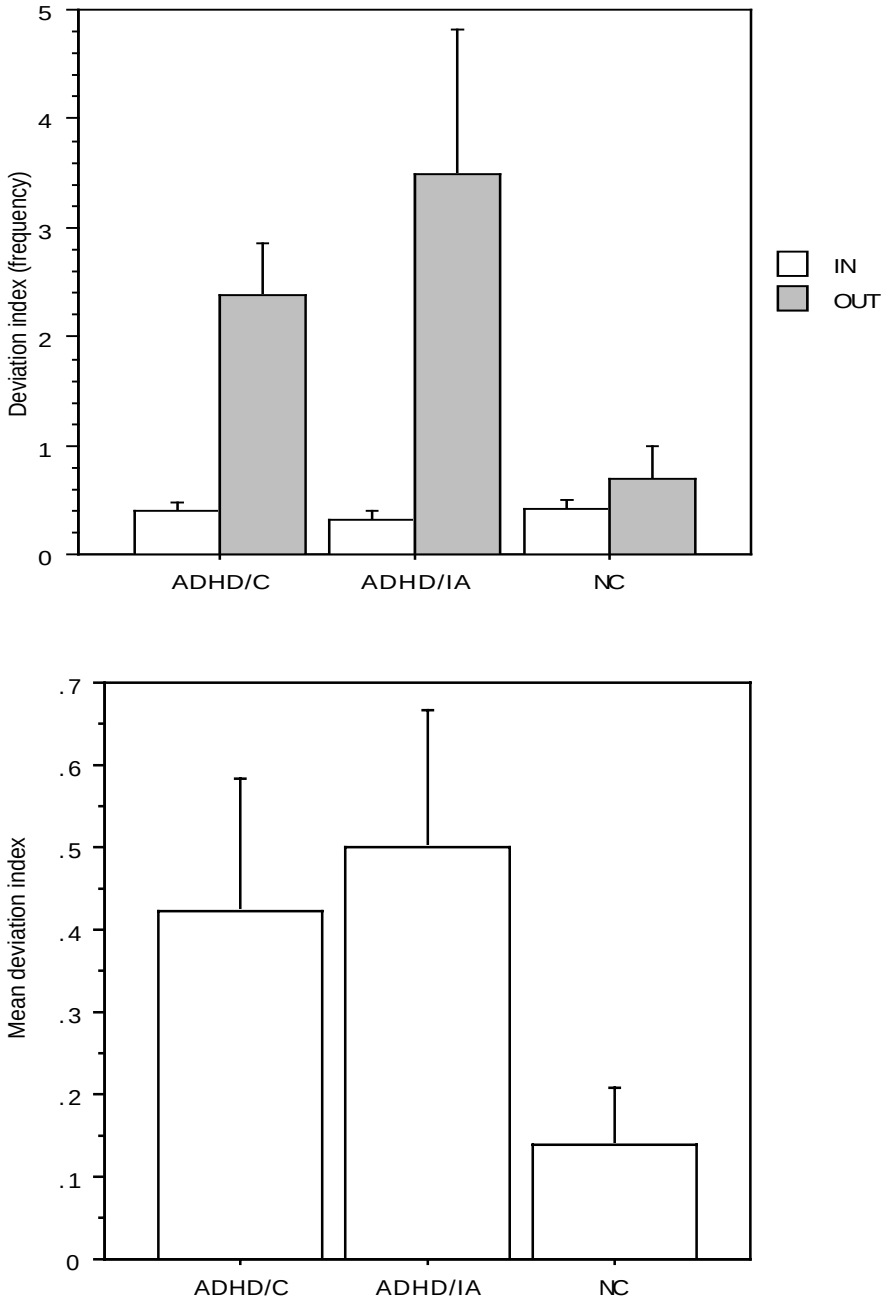

Figure 3.4: Top- Mean deviation score in participants who were included (IN) vs. excluded (OUT). ADHD/C/IN: OUT (11:6); ADHD/IA/IN: OUT (10:1); NC/IN: OUT (15:1); Bottom-the mean deviation score in participants who were included.

3.3.3 Baseline performance check:

To examine baseline performance across groups, overall RTs and error rates on the prime were compared for each task and no significant differences were found.

Table 3.3 Baseline performance for each task

	ADHD/C		ADHD/IA		NC	
	Letter	Spatial	Letter	Spatial	Letter	Spatial
RT on the prime (ms)	572.9 (51.8)	442.5 (42.4)	584.3 (42.9)	420.4 (44.5)	550.7 (50.2)	423.5 (37.9)
Error rates (%)	12.1 (3.4)	11.2 (4.7)	10.7 (2.3)	11.2 (2.8)	10.7 (3.1)	13.0 (4.8)

Note: Letter = letter matching task; Spatial = localization task; ADHD/C=attention deficit hyperactivity disorder/the combined subtype; ADHD/IA=attention deficit hyperactivity disorder/the predominantly inattentive subtype; NC= non-diagnosed controls; *SD*s are presented in parentheses.

3.3.4 Letter matching task

Preliminary analysis

A 3x3x2x2x2, mixed-design analysis of variance (ANOVA) was conducted on mean correct RTs with the diagnostic group (ADHD/C, ADHD/IA, or NC) as a between-subjects variable and priming condition (Control, Facilitation, or NP), and RSI (500 or 1000 ms), preceding trial type (different or same), and current trial type (different or same) as within-subject variables. There was a significant interaction between group, RSI, and priming, F (4,60) = 3.19, p = .02. This interaction pattern will be further examined in the following sections. There was a significant interaction between the four within-

subject variables, F (2,60) = 9.62, p = .0002. Due to complexity of interpreting higher order interactions, the dataset was divided into two parts, one with the Control and NP conditions and the other with the Control and Facilitation conditions. Priming condition significantly interacted with both preceding and current trial types, F (2,60) = 79.28, p < .0001 (see **Figure 3.5**) and RSI, F (2,60) = 4.59, p = .01. Preceding trial type significantly interacted with current trial type, F (2,60) = 7.25, p = .002. Main effects of both preceding and current trial types and priming were also significant, F (1,30) = 60.81 for the preceding trial type, F (1,30) = 40.21 for the current trial type, and F (2,30) = 33.45 for priming, all p < .0001. **Table 3.4** shows means and standard deviations for each experimental condition across groups.

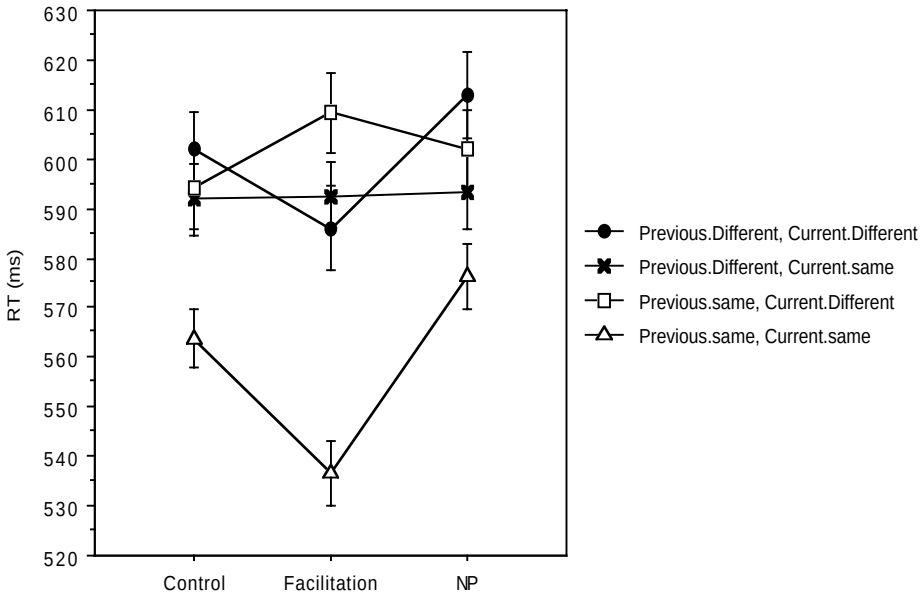

Figure 3. 5: Response times (RTs) for each priming condition as a function of preceding trial type and current trial type; NP = negative priming

Table 3. 4
Mean reaction times (in milliseconds) and error rates (in percentage) in parentheses across conditions

	ADHD/C (*n* = 10)		ADHD/IA (*n* = 9)		NC (*n* = 14)	
	Different	Same	Different	Same	Different	Same
			Previous Different			
500ms						
Control	618.7 (8.7)	589.7 (8.8)	617.5 (13.9)	612.0 (6.3)	579.9 (8.1)	567.5 (9.5)
Facilitation	591.3 (6.9)	595.7 (10.2)	593.4 (5.9)	626.9 (8.7)	560.2 (4.9)	571.3 (9.6)
NP	627.0 (10.8)	596.4 (8.9)	637.4 (10.9)	621.1 (8.7)	581.9 (11.9)	567.4 (13.5)
1000ms						
Control	613.1 (10.3)	596.2 (12.6)	631.5 (10.4)	616.7 (8.4)	575.5 (6.8)	586.3 (12.0)
Facilitation	611.8 (9.8)	589.0 (12.8)	617.8 (7.6)	605.7 (10.4)	564.8 (7.2)	582.8 (11.7)
NP	632.7 (11.4)	592.9 (14.3)	635.7 (12.0)	611.0 (10.3)	589.9 (8.9)	588.4 (16.9)
			Previous Same			
500ms						
Control	592.4 (6.6)	559.7 (7.8)	621.9 (4.2)	592.5 (8.0)	568.2 (7.3)	540.1 (8.6)
Facilitation	617.1 (11.7)	523.6 (2.2)	637.0 (9.5)	546.0 (3.4)	580.6 (12.2)	517.5 (3.0)
NP	605.7 (6.7)	569.3 (9.8)	630.3 (5.2)	617.0 (8.0)	585.8 (4.2)	549.2 (10.3)
1000ms						
Control	611.8 (10.9)	564.5 (10.5)	611.2 (4.0)	584.9 (8.1)	579.8 (5.8)	558.2 (9.7)
Facilitation	626.9 (13.5)	547.3 (5.7)	631.2 (8.6)	563.8 (5.5)	588.5 (12.6)	533.6 (4.9)
NP	618.2 (11.0)	581.3 (9.7)	606.1 (6.8)	595.3 (14.4)	583.8 (6.9)	566.6 (10.2)

Note: NP = negative priming; ADHD/C = attention deficit hyperactivity disorder/the combined subtype; ADHD/IA = attention deficit hyperactivity disorder/the predominantly inattentive subtype; NC = non-diagnosed controls

Control versus NP conditions

Hypothesis 1a: the overall effects of group, RSI, and priming condition on response times (RTs) and error rates

Responses on NP trials were expected to be significantly slower than those on Control trials. More errors were expected on NP trials than Control trials. It was hypothesized that there would be a significant interaction between group status, RSI, and priming conditions and specific hypotheses about the interactions involving group are put forth in the following section.

Two 3x2x2x2x2, mixed-design analysis of variances (ANOVA) were conducted on mean correct RTs and error rates with the diagnostic group (ADHD/C, ADHD/IA, or NC) as a between-subjects variable and priming condition (Control or NP), RSI (500 vs. 1000 ms), preceding trial type (different or same), and the current trial type (different or same) as within-subject variables.

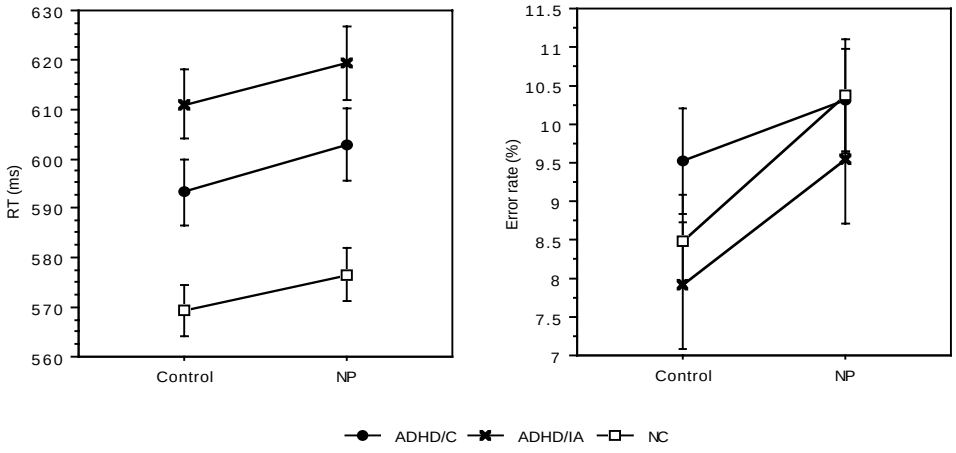

Figure 3.6: Response times (RTs) and error rates for each group as a function of priming condition; NP = negative priming; ADHD/C = attention deficit hyperactivity disorder/the combined subtype; ADHD/IA = attention deficit hyperactivity disorder/the predominantly inattentive subtype; NC = non-diagnosed controls

RT: Consistent with hypotheses, RTs on NP trials (*M* = 596.2ms; *SD* = 54.8) were significantly slower than those on Control trials (*M* = 588ms; *SD* = 52.0), *F* (1,30) = 18.63, *p* = .0002. Groups did not differ in terms of overall RT although there was a non-significant trend for the ADHD/IA group to be slower than the NC group, *F* (1,21) = 3.80, *p* = .06 (see **Table 3.5** for effect sizes). Group status significantly interacted with RSI and priming condition, *F* (2,30) =

3.53, p = .04. Responses on same trials (M = 581.4; SD = 48.7) were significantly faster than on different trials (M = 602.8; SD = 59.9), F (1,30) = 28.24, p < .0001. Responses on trials following same trials (M = 584.1; SD = 50.1) were also faster than those following different trials (M = 600.1; SD = 57.0), F (1.30) = 39.47, p < .0001. Same responses on the probe after same responses on the prime (M = 570.1; SD = 43.5) were faster than after different responses on the prime (M = 598.1; SD = 60.9) whereas responses on the prime did not affect significantly responses on the probe (M = 607.5, SD = 61.1 for different responses following different responses; M = 592.7, SD = 55.9 for same responses following different responses).

These findings were consistent with those in the Neill et al. study (1990) although overall RT in the current study was faster by 227ms and the mean error rate was twice high as that in the Neill et al. study (8.6% vs. 4.2%). In contrast to the Neill et al. study, preceding and current trial types significantly interacted with priming type, F (1,30) = 7.92, p = .009. As illustrated in **Figure 3.5**, negative priming effects were washed out when prime responses were different from probe responses [e.g. K<u>H</u>K<u>S</u>K-T<u>S</u>T<u>S</u>T: different (prime)-same (probe); H<u>K</u>H<u>K</u>H-T<u>K</u>T<u>S</u>T: same (prime)–different (probe)]. Thus, only sequences in which prime and probe responses match each other [e.g. K<u>C</u>K<u>D</u>K-S<u>C</u>S<u>D</u>S: different (prime)-different (probe); K<u>S</u>K<u>S</u>K-T<u>S</u>T<u>S</u>T: same (prime)-same (probe)] will be examined when analyzing NP effects in the following section.

Another difference from findings in the Neill et al. study (1990) was that instead of reaching significance, there was only a non-significant trend for responses on the probe (i.e. current trial type) to interact with responses on the prime (i.e. preceding trial type), F (1,30) = 3.26, p = .08. It should be noted, however, that when the Control condition was examined separately from the

NP condition, responses on the probe significantly interacted with responses on the prime, F (1,30) = 7.09, p = .01 as illustrated in **Figure 3.7**.

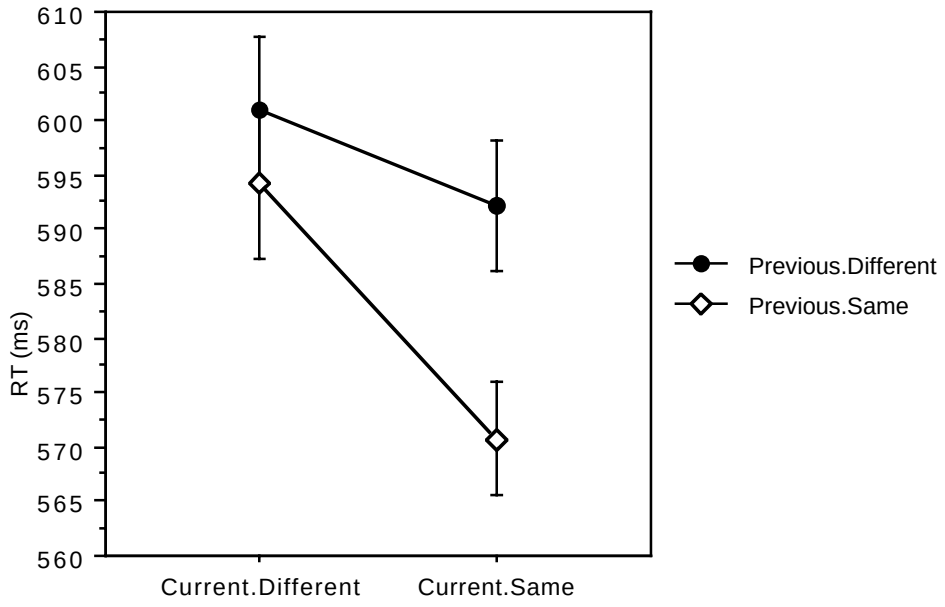

Figure 3.7: Response times for current trial type as a function of preceding trial type

Error rate: Groups did not differ significantly in terms of error rates. None of the interactions involving group status were significant. Consistent with hypotheses, more errors were made on NP trials (M = 10.1; SD = 3.1) than on Control trials (M = 8.6; SD = 2.9), F (1,30) = 8.10, p = .008. As the literature suggests (Krueger, 1978), more errors were made on same trials (M = 10.4; SD = 3.8) than on different trials (M = 8.4; SD = 2.9), F (1,30) = 5.59, p = .02. Responses on trials following same trials (M = 8.1; SD = 2.5) were more accurate than those following different trials (M = 10.7; SD = 3.7), F (1.30) = 15.55, p = .0004. There was a significant main effect of RSI on error rates, F (1,30) = 5.46, p = .03. That is, error rate was higher at 1000ms (M = 10.1; SD = 3.5) than at 500ms trials (M = 8.7; SD = 2.8). Priming condition did not

significantly interact with trial types. These findings were similar to those in the Neill et al. Study (1990); more errors were made on same trials than on different trials and on trials following same trials than those following different trials. In contrast to Neill et al. (1990), these two variables did not interact with each other. Further, there was a significant difference in error rates between the Control and the NP conditions.

Table 3.5 Effect sizes for group differences in RT and error rate

	ADHD/C vs. ADHD/IA	ADHD/C vs. NC	ADHD/IA vs. NC
RT	.31	.49	. 78
Error rate	.46	.19	. 26

Note. Effect sizes were based on Cohen's *d*. ADHD/C = attention deficit hyperactivity disorder/the combined subtype; ADHD/IA = attention deficit hyperactivity disorder/the predominantly inattentive subtype; NC = non-diagnosed controls

Summary

In sum, responses on NP trials were significantly slower than those on Control trials and error rates were higher on NP trials than on Control trials. This pattern in RT and error rate suggests that slowing down on NP trials was not a byproduct of accuracy. Groups did not differ significantly in RTs or error rates. Although there was a trend for the ADHD/IA group to be slower than the NC group, these groups did not differ significantly from each other in terms of error rate. Thus, the data did not indicate a speed-accuracy trade off across groups and priming conditions. Group status significantly interacted with RSI and priming condition. Both preceding and current trial types also significantly interacted with priming type. Specific interaction patterns among these variables are further examined in the following section.

Hypothesis 1b: the combined effects of RSI, trial type, and diagnosis on negative priming effects

The NC group was expected to take less time to show an inhibitory effect as indicated by a descending pattern as a function of RSI whereas the ADHD/C and ADHD/IA groups were expected to show an ascending pattern over time suggesting a build-up of inhibitory mechanism. The magnitude of negative priming as indicated by difference scores was expected to increase in the order of the ADHD/C, NC, and ADHD/IA groups.

Given that the magnitude of negative priming was to be assessed at only two RSIs, types of time course were expected to be three-fold. First, an ascending pattern would emerge if negative priming was building up between 500ms and 1000s. Second, a descending pattern would emerge if a negative priming effect was dissipating during this time frame. Finally, the slope would be flat if there is no change in NP during this time, suggesting one of two possibilities: 1) the NP effect reached a peak before 500ms and remained stable between 500s and 1000ms if NP effect is significantly greater than zero. Or 2) inhibitory mechanism might be inactive between the two points due to a deficient inhibitory mechanism or because the timing happened during the slow buildup or dissipation.

Negative priming scores based on RTs were derived for each participant by the difference between the mean RT on Control trials and the mean RT on NP trials. A positive score indicated slowing on negative priming trials whereas a negative score indicated speeding up. A 3 x 2 x 2 repeated measure ANOVA was conducted on negative priming scores with group as a between subject variable, RSI (500 vs. 1000 ms), and the trial type (different or same) as within-subject variables. Then one-tailed t-tests were conducted for each group at each RSI condition to see if the magnitude of negative priming demonstrated by each

group was significantly greater than zero, indicating intact or normal negative priming (see **Figure 3.8**). Effect sizes (Cohen's *d*) were calculated for group differences as a function of RSI (see **Table 3.5**). **Figure 3.8** illustrates negative priming scores for each group as a function of RSI.

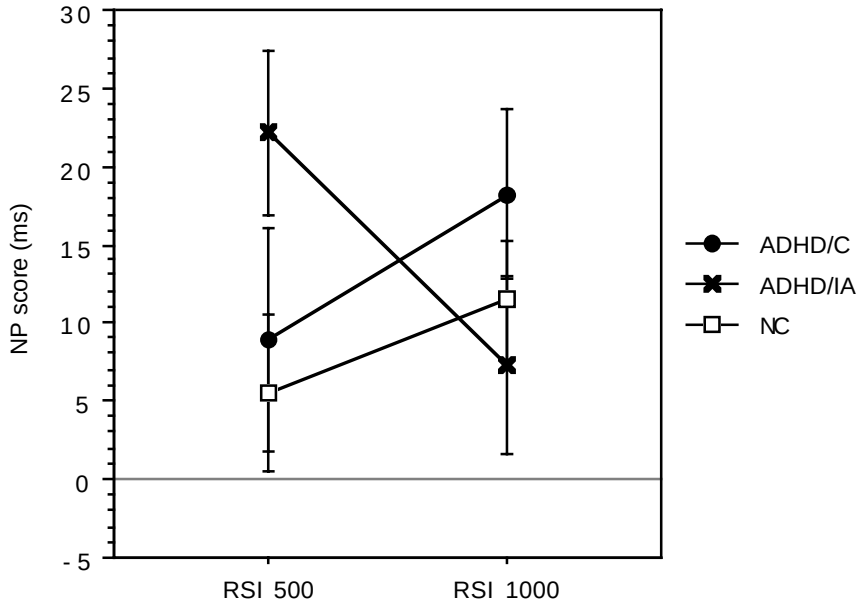

Figure 3.8: Difference scores of negative priming in RTs for the letter-matching task as a function of RSI in each group. Lines are accompanied by S.E.M.

Overall, there was a significant interaction between group and RSI, F (2,30) = 4.46, p = .02. All other interactions and main effects failed to reach significance. When groups were examined separately, there was a significant effect for RSI only for the ADHD/IA group, F (1,8) = 6.61, p = .03, not for the ADHD/C and NC groups. That is, the ADHD/IA group showed a sharp decline of NP effects as a function of RSI whereas neither ADHD/C nor NC groups showed significant changes in NP. One-tailed t-tests showed that negative priming in the ADHD group was significant only at 500ms (22.2ms), t (8) =

4.2, p = .002, indicating that NP effects dissipated by 1000ms (7.3ms). On the contrary, the magnitude of NP in both ADHD/C (8.9ms) and NC groups (5.5) at 500ms was not significantly greater than zero, but both groups showed significant negative priming at 1000ms, indicating a build-up (18.2ms for ADHD/C; 11.5ms for NC), t (9) = 4.2, p = .002 for the ADHD/C group and t (13) = 11.5, p = .005. Finally, effect size calculations for group differences indicated that the magnitude of negative priming at 500ms in the ADHD/IA group was greater than both the ADHD/C and NC groups whereas the difference between the ADHD/C group and the NC group was negligible. The magnitude of negative priming at 1000ms in the ADHD/C group was greater than the ADHD/IA group whereas the effect sizes for the NC group compared to both ADHD groups were in the small range. **Table 3.6** shows effect sizes for group differences as a function of RSI.

Table 3.6 Effect sizes for group differences in NP as a function of RSI

RSI	ADHD/C vs. ADHD/IA	ADHD/C vs. NC	ADHD/IA vs. NC
500ms	.66	.17	. 86
1000ms	.62	.44	. 27

Note. Effect sizes were based on Cohen's *d*. ADHD/C = attention deficit hyperactivity disorder/the combined subtype; ADHD/IA = attention deficit hyperactivity disorder/the predominantly inattentive subtype; NC = non-diagnosed controls; RSI = response to stimulus interval

Control vs. Facilitation conditions

Hypothesis 2a: the overall effects of diagnosis, RSI, and priming condition on response times (RTs) and error rates

Responses on Facilitation trials were expected to be significantly faster than those on Control trials. Fewer errors were expected on Facilitation trials

than Control trials. It was hypothesized that there would be a significant interaction between group status, RSI, and priming conditions and specific hypotheses about the interactions involving group are put forth in the following section.

As illustrated in **Figure 3.5**, facilitation effects were cancelled out when only half of target letters were repeated (KHKSK-TSTST: different-same and HKHKH-TKTST: same-different). Thus, only sequences involving repetition of both target letters (KCKDK-SCSDS: different-different and KSKSK-TSTST: same-same) were used for analyses.

Two 3x2x2x2, mixed-design analysis of variances (ANOVAs) were conducted on the mean correct RTs and error rates with the diagnostic group (ADHD/C, ADHD/IA, or NC) as a between-subjects variable and priming conditions (Control or Facilitation), RSI (500 vs. 1000 ms), and the trial type (different or same) as within-subject variables.

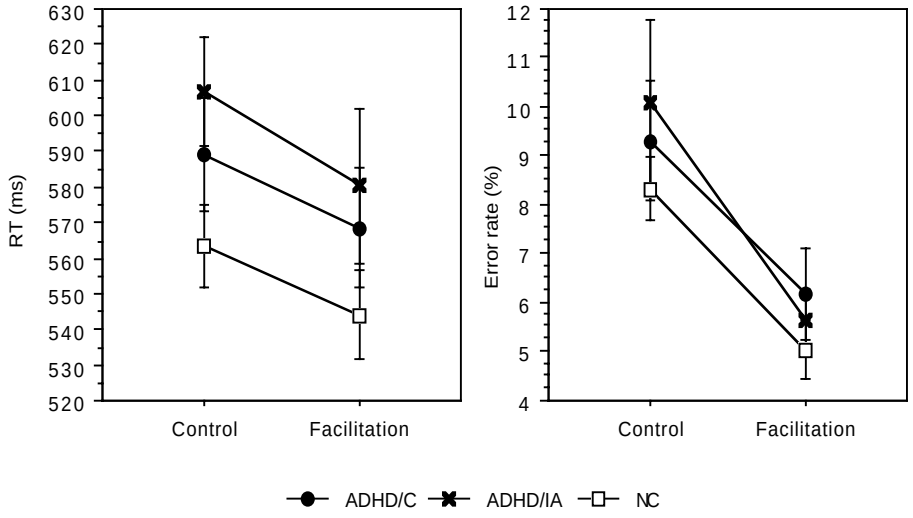

Figure 3.9: Response times (RTs) and error rates for each group as a function of priming condition

RT: RTs on facilitation trials (M = 561.3ms; SD = 55.3) were significantly faster than those on Control trials (M = 582.9ms; SD = 48.3), F (1,30) = 57.84, $p < .0001$. Groups did not differ in terms of overall RT although there was a non-significant trend for the ADHD/IA group to be slower than the NC group, F (1,21) = 3.58, p = .07 (see **Table 3.7** for effect sizes). Group status significantly interacted with RSI and priming condition, F (2,30) = 3.46, p = .04; The specific pattern for each group will be examined in the following section. Responses on same trials (M = 550.2; SD = 44.7) were significantly faster than on different trials (M = 594.1; SD = 60.8), F (1,30) = 84.42, $p <$ .0001. Priming condition significantly interacted with trial type, F (1,30) = 5.21, p = .03 and with RSI, F (1,30) = 19.90, p = .0001; the specific pattern for each group will be also examined in the following section.

Error rate: Groups did not differ significantly in terms of error rates. None of interactions involving group status was significant. Fewer errors were made on Facilitation trials (M = 5.5; SD = 2.4) than on Control trials (M = 9.1; SD = 3.6), F (1,30) = 8.10, p = .008. Priming condition significantly interacted with RSI, F (1,30) = 7.09, p = .01. That is, fewer errors were made on Facilitation trials at 500ms (M = 4.3; SD = 2.9) than at 1000ms (M = 6.7; SD = 3.1) whereas error rates were comparable on Control trials at both RSIs (M = 9.0, SD = 4.7 for 500ms; M = 9.2, SD = 4.8 for 1000ms). More errors were made on different trials (M = 8.2; SD = 3.9) than on same trials (M = 6.5; SD = 3.5), F (1,30) = 4.61, p = .04. Priming condition did not significantly interact with trial type.

Table 3.7 Effect sizes for group differences in RT and error rate

	ADHD/C vs. ADHD/IA	ADHD/C vs. NC	ADHD/IA vs. NC
RT	.27	.52	. 76
Error rate	.07	.42	. 46

Note. Effect sizes were based on Cohen's *d*. ADHD/C = attention deficit hyperactivity disorder/the combined subtype; ADHD/IA = attention deficit hyperactivity disorder/the predominantly inattentive subtype; NC = non-diagnosed controls

Summary

In sum, responses on Facilitation trials were significantly faster than those on Control trials and error rates were lower on Facilitation trials than on Control trials. Groups did not differ significantly both in RT and error rate. Although the ADHD/IA group was slower than the NC group at a non-significant level, the two groups did not differ significantly from each other in error rate. Thus, the data did not indicate a speed-accuracy trade off across groups and priming conditions. Group status significantly interacted with RSI and priming condition. Priming conditions significantly interacted with trial type and with RSI. Specific interaction patterns among these variables are further examined in the following section.

Hypothesis 2b: the combined effects of RSI and diagnosis on facilitation effects

Both ADHD groups were expected to show smaller facilitation effects than the NC group. No significant differences were expected between the ADHD/IA and the ADHD/C groups.

Facilitation scores were obtained for each participant by the difference between the mean RT on Control trials and the mean RT on Facilitation trials. A positive score indicated speeding up. The greater the score was, the greater the magnitude of facilitation occurred. A 2 x 2 repeated measure ANOVA was conducted on facilitation scores for each group with RSI (500 vs. 1000 ms) and the trial type (different or same) as within-subject variables. Then one-tailed t-tests were conducted for each RSI condition to see if the magnitude of

facilitation demonstrated by each group was significantly smaller than zero, indicating intact or normal facilitation. Effect sizes were calculated for group differences as a function of RSI (see **Table 3.8**). Figure 12 illustrates facilitation scores for each group as a function of RSI.

Overall, there was significant interaction between group and RSI, F (2,30) = 3.46, p = .04. The main effect of RSI was significant only in two ADHD subtypes, F (1,9) = 16.69, p = .003 for ADHD/C, F (1,8) = 5.34, p = .050 for ADHD/IA. That is, the magnitude of facilitation in both ADHD groups was significantly greater at 500ms (32ms for ADHD/C; 35ms for IA) than at 1000ms (9ms for ADHD/C; 17ms for IA) whereas that in the NC group did not change significantly as a function of RSI (21ms for 500ms; 18ms for 1000ms). One-tailed t-tests showed that facilitation effects were significantly greater than zero at both RSIs in all three groups. **Figure 3.10** illustrates facilitation effects for each group as a function of RSI. Effect sizes are presented in **Table 3.8**. **Figure 3.11** illustrates the time course of negative priming and facilitation in each group.

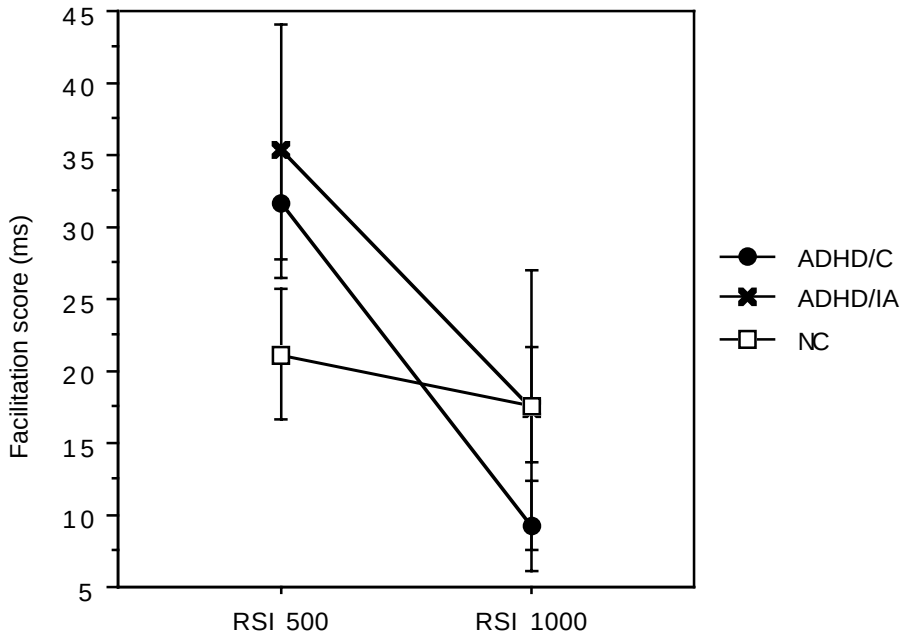

Figure 3.10: Difference scores of facilitation for letter matching task after 500ms and 1000ms RSI in the ADHD/C, ADHD/IA, and NC groups. Lines are accompanied by S.E.M.

Table 3.8
Effect sizes for group differences in facilitation in the letter-matching task

	ADHD/C vs. ADHD/IA	ADHD/C vs. NC	ADHD/IA vs. NC
500ms	.18	.67	.65
1000ms	.39	.63	.01

Note: Effect sizes were based on Cohen's *d*.

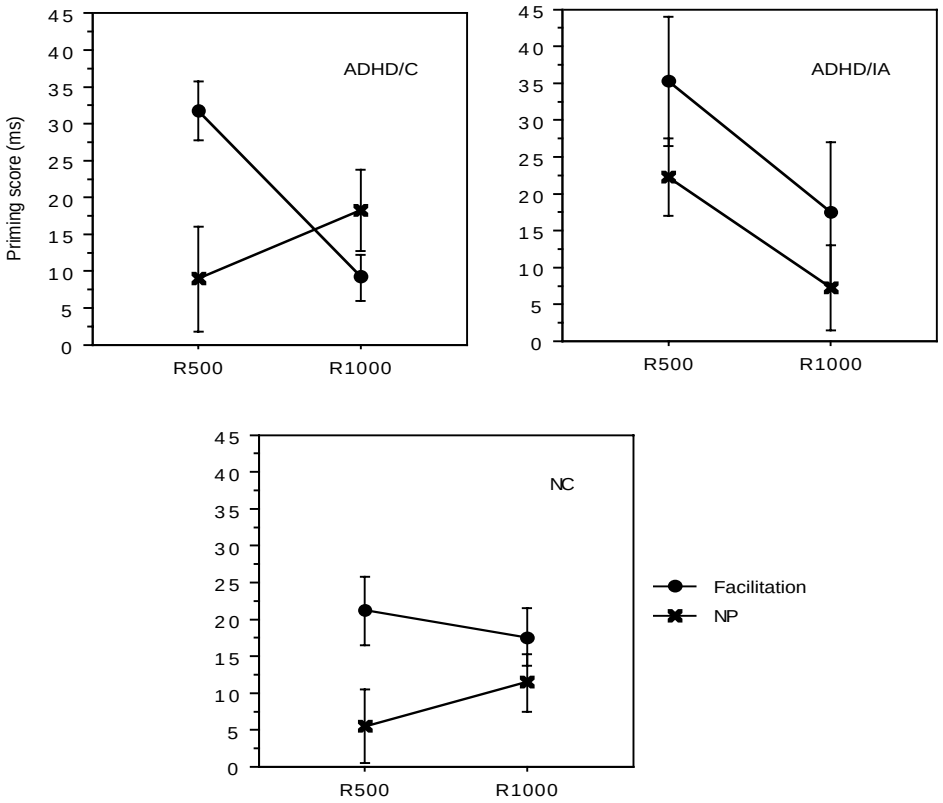

Figure 3.11: The Time course of negative priming and facilitation in each group for the letter-matching task

3.3.5 Localization task

Preliminary analysis

A 3x3x2x2, mixed-design analysis of variance (ANOVA) was conducted on mean correct RTs with the diagnostic group (ADHD/C, ADHD/IA, or NC) as a between-subjects variable and priming conditions (Control, Facilitation, or NP), RSI (500 vs. 1000 ms), and target identity (mismatch vs. match) as within-subject variables.

RTs were significantly faster at 1000ms (M = 436.8; SD = 43.6) than at 500ms (M = 463.6; SD = 49.3) and RSI significantly interacted with target identity alone, F (1,33) = 5.87, p = .02 as well as combined with group, F (2,33) = 5.91, p = .006 as illustrated in **Figure 3.12**. RTs in the mismatch condition were also significantly slower than in the match condition, F (1,33) = 4.90, p = .03 and target identity significantly interacted with group, F (2,33) = 5.79, p = .007. The main effect of priming condition was significant, F (2,66) = 49.50, p < .0001 indicating that responses were slowest in the order of the Control, NP, and Facilitation conditions. Priming condition significantly interacted with RSI, F (2,66) = 6.07, p = .004, as well as with target identity, F (2,66) = 20.41, p < .0001. Due to multiple interactions among variables, the data set was divided into two parts, one with the Control and Facilitation conditions and the other with the Control and NP conditions to gain better understanding of relationships among variables. Mean RTs and error rates in all experimental conditions are presented in **Table 3.9**.

Table 3.9

Mean reaction times (in milliseconds) and error rates (in percentage) in parentheses across conditions

	ADHD/C (n = 11)		ADHD/IA (n = 9)		NC (n = 16)	
	Mismatch	Match	Mismatch	Match	Mismatch	Match
500ms						
Control	491.2 (6.5)	493.6 (10.4)	475.2 (6.7)	470.1 (11.7)	463.8 (8.1)	477.0 (9.7)
Facilitation	474.9 (8.7)	461.7 (7.1)	458.2 (8.4)	437.1 (10.0)	432.2 (5.4)	418.6 (4.9)
NP	484.3 (6.9)	481.9 (12.8)	475.7 (9.2)	458.1 (13.6)	456.7 (9.3)	463.8 (11.8)
1000ms						
Control	463.4 (11.3)	479.7 (13.3)	446.1 (10.5)	455.3 (8.2)	449.3 (10.0)	451.1 (13.7)
Facilitation	437.7 (6.5)	432.5 (8.6)	409.3 (6.5)	402.7 (5.5)	401.2 (5.3)	393.5 (5.0)
NP	448.0 (9.4)	457.6 (9.9)	437.0 (10.4)	434.9 (9.2)	441.3 (9.4)	436.7 (13.8)

Note: NP = negative priming; ADHD/C = attention deficit hyperactivity disorder/the combined subtype; ADHD/IA = attention deficit hyperactivity disorder/the predominantly inattentive subtype; NC = non-diagnosed controls

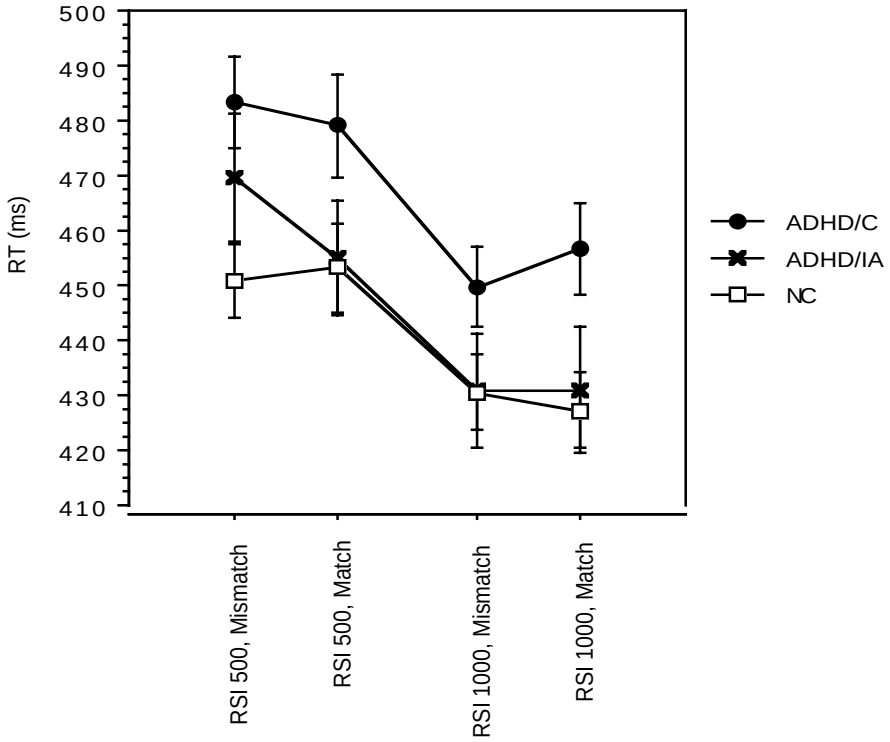

Figure 3.12: RTs as a function of RSI and target identity in each group.

Control versus NP conditions

Hypothesis 1a: the overall effects of diagnosis, RSIs, and priming conditions on response times (RTs) and error rates on the probe

RTs on NP trials were expected to be significantly slower than those on Control trials. More errors were expected on NP trials than Control trials. It was hypothesized that there would be a significant interaction between group status, RSI, and priming conditions and specific hypotheses about the interactions involving group are put forth in the following section.

Two 3x2x2x2, mixed-design analysis of variances (ANOVAs) were conducted on mean correct RTs and error rates with the diagnostic group (ADHD/C, ADHD/IA, or NC) as a between-subjects variable and, priming conditions (Control or NP), RSI (500 vs. 1000 ms), and target identity (mismatch vs. match) as within-subject variables.

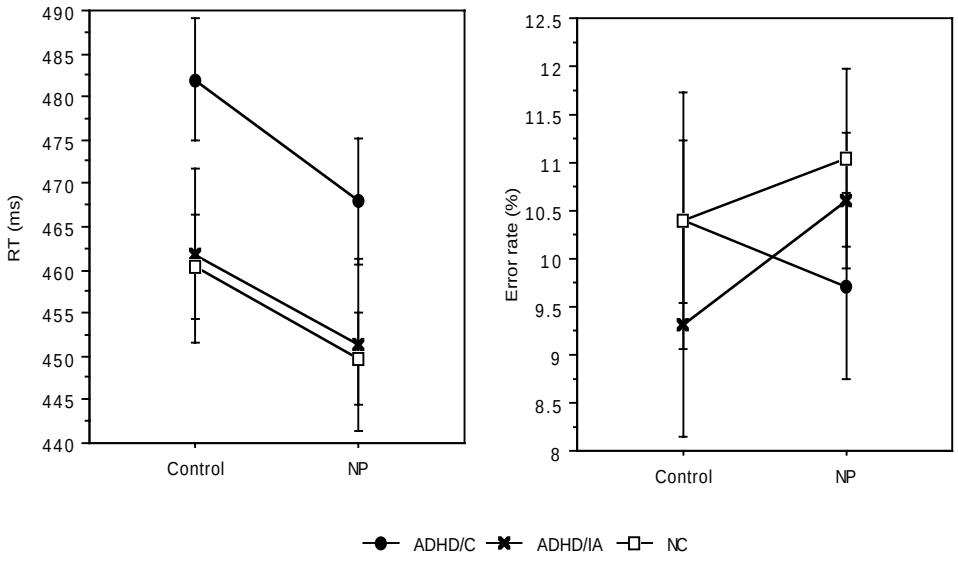

Figure 3.13: Response times (RTs) and error rates for the localization task as a function of priming condition (Control vs. NP)

RT: The main effect of group effect was not significant, but two interactions involving group status were significant: (1) target identity, F (2,33) = 4.85, p = .01 and RSI and target identity, F (2,33) = 8.02, p = .001. Specific interaction pattern will be examined in the following section. There was a significant main effect of priming, F (1,33) = 20.54, $p < .0001$. Contrary to prediction, responses on Control trials (M = 467.3; SD = 46.6) were significantly slower than responses on NP trials (M = 455.7; SD = 44.9). Priming effect was moderated by target identity, F (1,33) = 5.55, p = .02. Responses at 1000ms (M = 449.7;

SD = 46.6) were significantly faster than at 500ms (*M* = 473.3; *SD* = 49.2), *F* (1,33) = 18.35, *p* = .0001. All other main effects and interactions failed to reach significance.

Table 3.10 Effect sizes for group differences in RT and error rate

	ADHD/C vs. ADHD/IA	ADHD/C vs. NC	ADHD/IA vs. NC
RT	.36	.49	.03
Error rate	.02	.12	.17

Note. Effect sizes were based on Cohen's *d*. ADHD/C = attention deficit hyperactivity disorder/the combined subtype; ADHD/IA = attention deficit hyperactivity disorder/the predominantly inattentive subtype; NC = non-diagnosed controls

Error rate: The main effect of group was not significant, but the group status significantly interacted with both RSI and target identity, *F* (2,33) = 3.34, *p* = .048. The main effect of target identity was significant, *F* (1,33) =17.41, *p* = .0002. Error rate was greater in the match condition (*M* = 11.7; *SD*= 5.4) than in the mismatch condition (*M* = 9.0; *SD* = 4.4). All other interactions and main effects failed to reach significance.

Findings from Tipper's study (1995) were not replicated in the current study. First, negative priming did not occur in any of the experimental conditions involving RSI and target identity and in any groups in the current study. Instead, significant facilitation occurred. Second, the main effect of target identity was significant in the current study. Potential explanations for discrepant findings will be examined in the discussion section.

Hypothesis Two: the combined effects of RSI, target identity, and diagnosis on negative priming effects

The NC group was expected to take less time to show an inhibitory effect as indicated by a descending pattern as a function of RSI whereas the

ADHD/C and ADHD/IA groups were expected to show an ascending pattern over time suggesting a build-up of inhibitory mechanism. The magnitude of negative priming as indicated by difference scores was expected to increase in the order of the ADHD/C, NC, and ADHD/IA groups.

Negative priming scores for RTs were derived for each participant by the difference between the mean RT on Control trials and the mean RT on negative priming trials in the match vs. mismatch conditions and the two RSI conditions. A positive score indicated slowing down on negative priming trials whereas a negative score indicated speeding up. A one-way repeated measure ANOVA was conducted on facilitation scores for each group with RSI (500 vs. 1000 ms) as a within-subject variable. Then one-tailed t-tests were conducted for each RSI condition to see if the magnitude of facilitation demonstrated by each group was significantly smaller than zero instead of greater than zero since analysis on RT showed faster RT on NP trials. **Figure 3.14** illustrates negative priming scores for each group as a function of RSI.

Match: Neither the main effect of group nor the interaction between group and RSI were significant. The main effect of RSI was not significant in any of the three groups. Simple t-tests revealed that the ADHD/C and NC groups showed significant facilitation at both RSIs whereas the ADHD/IA group showed significant facilitation only at 1000ms (See **Figure 3.14**).

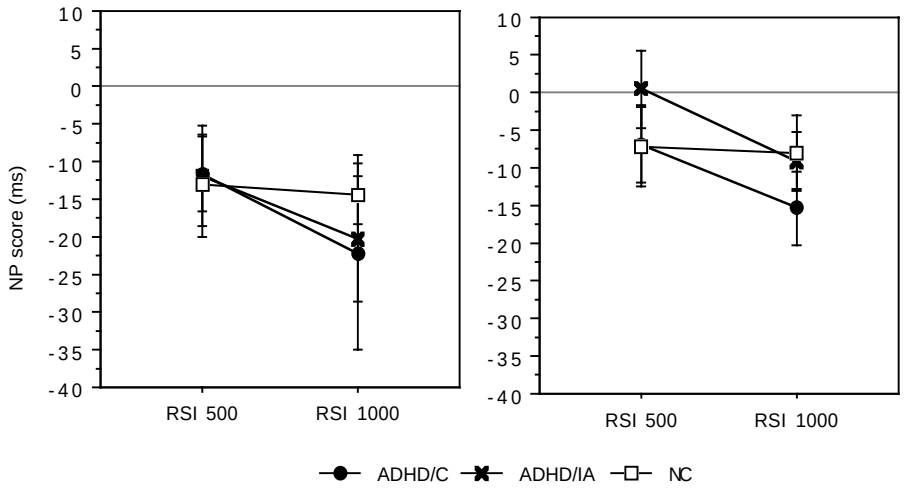

Figure 3.14: Difference scores of negative priming in RTs for the localization task as a function of RSI in the match condition (left) and in the mismatch condition (right)

Mismatch: Neither the main effect of group nor the interaction between group and RSI were significant. The magnitude of facilitation was greater at 1000ms than at 500ms at a non-significant level, $F(1,35) = 3.62$, $p < .07$. Simple t-tests revealed that the ADHD/C and ADHD/IA groups showed significant facilitation at 1000ms whereas the NC group showed only a non-significant trend for facilitation at 1000ms (See **Figure 3.14**).

Control vs. Facilitation conditions

Hypothesis 2a: the overall effects of diagnosis, RSI, and priming condition on response times (RTs) and error rates

Responses on Facilitation trials were expected to be significantly faster than those on Control trials. Fewer errors were expected on Facilitation trials than Control trials. It was hypothesized that there would be a significant interaction

between group status, RSI, and priming conditions and specific hypotheses about the interactions involving group are put forth in the following section.

As in the letter-matching task, facilitation requires repetition of targets. Thus, facilitation effects were examined only when probe targets were identical both in location and the identity of prime targets (the match condition) (see **Figure 3.2 Panel A**).

Two 3x2x2, mixed-design analysis of variances (ANOVAs) were conducted on the mean correct RTs with the diagnostic group (ADHD/C, ADHD/IA, or normal s) as a between-subjects variable and priming conditions (Control or Facilitation) and RSI (500 vs. 1000 ms) as within-subject variables.

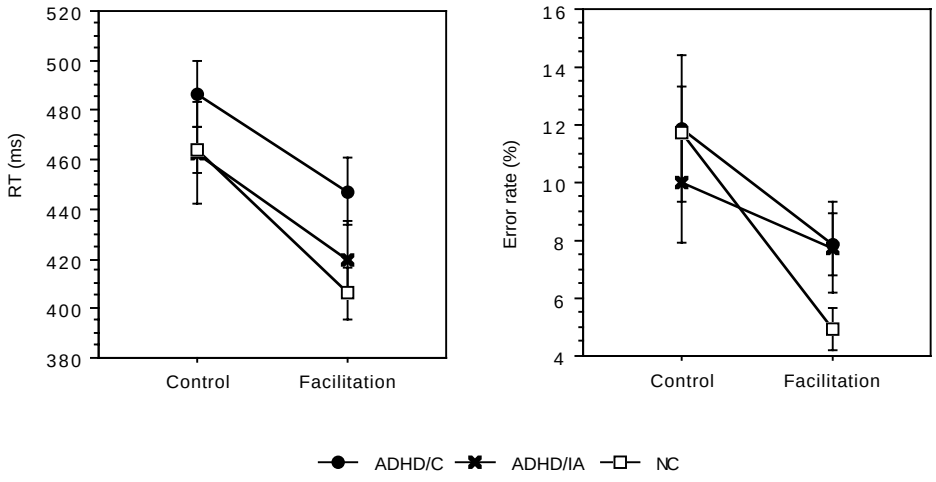

Figure 3.15: Response times (RTs) and error rates for the localization task as a function of priming condition (Control vs. Facilitation)

***RT*:** RTs on Facilitation trials (M = 422.1ms; SD = 46.3) were significantly faster than those on Control trials (M = 470.6ms; SD = 46.5), F (1,33) = 94.70, $p < .0001$. Groups did not differ in terms of overall RT although there was a

non-significant trend for the ADHD/C group to be slower than the NC group, F (1,25) = 4.14, p = .05 (see **Table 3.11**). None of interactions involving Group status was significant. Responses at 1000ms (M = 434.3ms; SD = 44.4) were significantly faster than on responses at 500ms (M = 458.4ms; SD = 51.8), F (1,33) = 12.31, p = .001. Priming condition significantly interacted with RSI, F (1,33) = 4.20, p = .05; the specific interaction pattern will be also examined in the following section.

Table 3.11 Effect sizes for group differences in RT and error rate

	ADHD/C vs. ADHD/IA	ADHD/C vs. NC	ADHD/IA vs. NC
RT	.54	.75	.15
Error rate	.19	.33	.14

Note. Effect sizes were based on Cohen's *d*. ADHD/C = attention deficit hyperactivity disorder/the combined subtype; ADHD/IA = attention deficit hyperactivity disorder/the predominantly inattentive subtype; NC = non-diagnosed controls

Error rate: Groups did not differ significantly in terms of error rates. Fewer errors were made on Facilitation trials (M = 6.5; SD = 3.8) than on Control trials (M = 11.3; SD = 6.8), F (1,33) = 20.86, p < .0001. Group status significantly interacted with RSI, F (2,33) = 4.09, p = .03. That is, the ADHD/IA group made significantly more errors at 500ms (M = 10.9; SD = 7.3) than at 1000ms (M = 6.9; SD = 3.3) whereas both the ADHD/C and NC groups showed a non-significant trend for the mean error rate at 1000ms (M = 10.0; SD = 6.6) to be greater than at 500ms (M = 7.9; SD = 4.1), F (1,25) = 4.10, p = .05.

In sum, responses on Facilitation trials were significantly faster than those on Control trials and error rates were lower on Facilitation trials than on Control trials. Groups did not differ significantly both in RT and error rate. Although the ADHD/C group was slower than the NC group at a non-significant level, the two groups did not differ significantly from each other in error rate. Thus, the data did not indicate a speed-accuracy trade off across

groups and priming conditions. Group status significantly interacted with RSI and priming condition. Priming conditions significantly interacted with trial type and with RSI. Specific interaction patterns among these variables are further examined in the following section.

Hypothesis 2b: the combined effects of RSI and diagnosis on facilitation effects

Both ADHD groups were expected to show smaller facilitation effects than the NC group. No significant differences were expected between the ADHD/IA and the ADHD/C groups.

Facilitation scores were obtained for each participant by the difference between the mean RT on Control trials and the mean RT on Facilitation trials at each RSI in the match condition. A positive score indicated benefits from repetition of target location by speeding up whereas a negative score indicated slowing down.

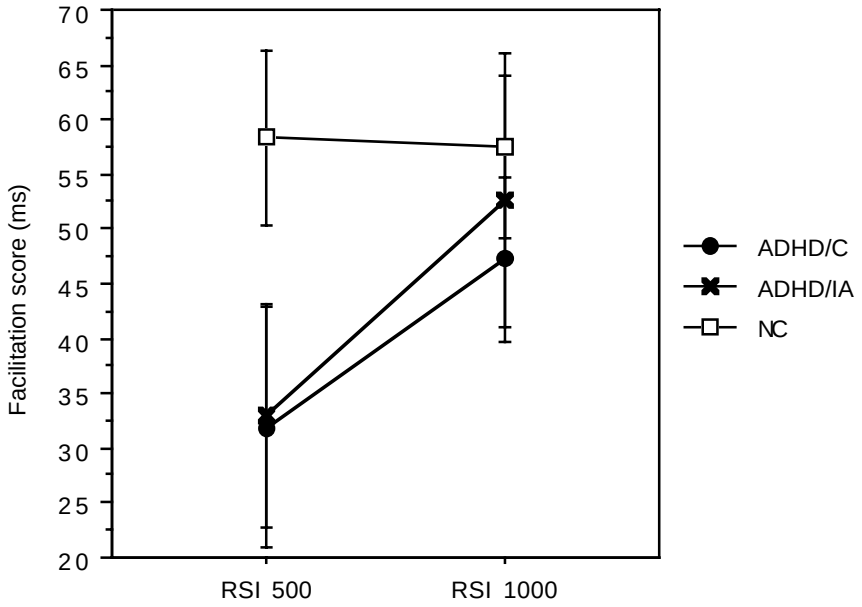

Figure 3. 16: Difference scores of facilitation in the match condition for localization task as a function of RSI in ADHD/C, ADHD/IA, and NC. Lines are accompanied by S.E.M.

The magnitude of facilitation was significantly greater in the 1000ms than in the 500ms, F (1,33) = 4.20, p = .049. The main effect of group and interaction between RSI and group were not significant. When each group was examined separately, the effect of RSI was significant only in the ADHD/IA group, F (1,8) = 6.10, p = .04. The magnitude of facilitation in the ADHD/IA group was greater at 1000ms (52.5ms) than at 500ms (33.0ms), indicating a build-up. Although the RSI effect in the ADHD/C group failed to reach significance, effect size calculation (d = .49) revealed that the magnitude of facilitation was greater at 1000ms (47.2ms) than at 500ms (31.9ms), indicating a build-up like the ADHD/IA group. In contrast to two ADHD subtypes, the magnitude of facilitation in the NC group remained stable as a function of RSI (58.4ms at 500ms; 57.5ms at 1000ms). **Figure 3.16** illustrates facilitation

effects as a function of RSI for each group. Since positive priming was indicated as illustrated in **Figure 3.15**, one-tailed t-tests were conducted to examine if the magnitude of facilitation was significantly greater than zero. All groups showed significant facilitation at both RSIs. Effect size calculations for group differences revealed that the magnitude of facilitation at 500ms in the NC group was greater than both ADHD groups (See **Table 3.12**). Differences between the ADHD/C group and the ADHD/IA group were negligible at both RSIs.

Table 3.12 Effect sizes for facilitation effects in the match condition

	ADHD/C vs. ADHD/IA	ADHD/C vs. NC	ADHD/IA vs. NC
500ms	.03	.82	.77
1000ms	.11	.27	.15

Note: ADHD/C = attention deficit hyperactivity disorder/the combined subtype; ADHD/IA = attention deficit hyperactivity disorder/the predominantly inattentive subtype; NC = non-diagnosed controls

Chapter 4

Conclusions and discussion

4.1 Summary of the results

Overall, there was a significant interaction between group and RSI both for negative priming and facilitation, although the pattern of group relationships differed for these two processes. That is, the profile of negative priming for the ADHD/IA group was different from that of both the ADHD/C and NC groups whereas the ADHD/C and NC groups showed a similar pattern. The facilitation profiles for both the ADHD/C and ADHD/IA types were similar to each other, but different from the NC group.

4.1.1 Negative priming

The Letter-matching task

The ADHD/IA type showed greater negative priming than both the ADHD/C group (effect size for the group difference d = .66) and the NC group (d = .86) at 500ms but a sharp decay by 1000ms. The ADHD/C group and NC groups showed a significant negative priming effect only at 1000ms while showing an ascending trend between 500ms and 1000ms, suggesting a build-up in the inhibitory process. The ADHD/C group and NC groups, unlike the ADHD/IA group, did not show a sharp decay in negative priming at1000ms.

The Localization task

Findings from Tipper's study with the non-diagnosed group (1995) were not replicated in the current study. Negative priming did not occur for the localization task at either RSI for any group. Instead, significant facilitation occurred. However, the main effect of target identity (match versus mismatch) was significant. Several factors might have contributed to the discrepancy in findings: 1) The mean error rate in Tipper's study was very low (1.5%) compared to the mean error rate in the current study (9.0%). In addition to the lower error rate, the median RT was slower (450ms*) than in the current study (432ms), suggesting the possibility of a speed-accuracy trade off in Tipper's study. That is, participants in the current study may have focused more on the speed and inhibited prime distractors less than in studies in which participants focus more on the accuracy. Thus, exposure to distractors without adequate inhibition on the prime might have led to reversed priming (facilitation) on the probe as the literature suggests (see 2.3.2). The ratio of mismatch to match trials was different (2:1 in Tipper's study vs. 1:1 in the current study). 3) The ratio of Control trials to NP trials was also different (2:1 in Tipper's study vs. 1:1 in the current study). In addition, Facilitation trials were added to the current study and the ratio of Control, Facilitation, NP trials were 1:2:1. Given that the magnitude of facilitation was significantly greater in the match condition than in the mismatch and half the trials were in the Facilitation condition and their target identity were matched, participants might have adopted the strategy with which they focused on repetition of targets. 4) Processes that are not inhibitory in nature might have been activated during the task. One possibility is alignment, which is related to expectations of where

* Mean of median RT was estimated based on Figure 5 in Tipper's study (1995) since the table for specific numbers was not reported. Mean of median RT in the current study was reported for comparison purposed although the study was based on mean RTs.

stimuli will appear. For instance, if a participant saw a prime trial in which the target appeared on the left and the distractor appeared on the bottom, he might expect a probe trial with the bottom location whether it serves as a target or a distractor. Thus, a subject might respond more quickly if a probe trial involves the bottom location. 5) Using letters as stimuli might have been a confounding factor in that the task might have not served as a localization task. Thus, objects that are three-dimensional and do not involve language processes might be a better stimulus set for localization tasks.

4.1.2 Facilitation

The Letter-matching task

The ADHD/C and ADHD/IA groups showed a sharp decline in facilitation between 500ms and 1000ms, whereas the magnitude of facilitation for the NC group remained stable as a function of RSI.

The Localization task

The ADHD/C and ADHD/IA groups showed a steep build-up in facilitation between 500ms and 1000ms, whereas the magnitude of facilitation in the NC group remained stable as a function of RSI. The Table 4.1 shows effects sizes for group differences in facilitation in the letter-matching and localization tasks. The Figure 4.1 illustrates facilitation in both tasks for each group.

Table 4.1 Effect sizes for group differences in facilitation for both tasks

	ADHD/C vs. ADHD/IA		ADHD/C vs. NC		ADHD/IA vs. NC	
RSI	Letter	Spatial	Letter	Spatial	Letter	Spatial
500ms	.18	.03	.67	.82	.65	.77
1000ms	.39	.11	.63	.27	.01	.15

Note: Letter = Letter-matching task; Spatial = Localization task; ADHD/C = attention deficit hyperactivity disorder/the combined subtype; ADHD/IA = attention deficit hyperactivity disorder/the predominantly inattentive subtype; NC = non-diagnosed controls

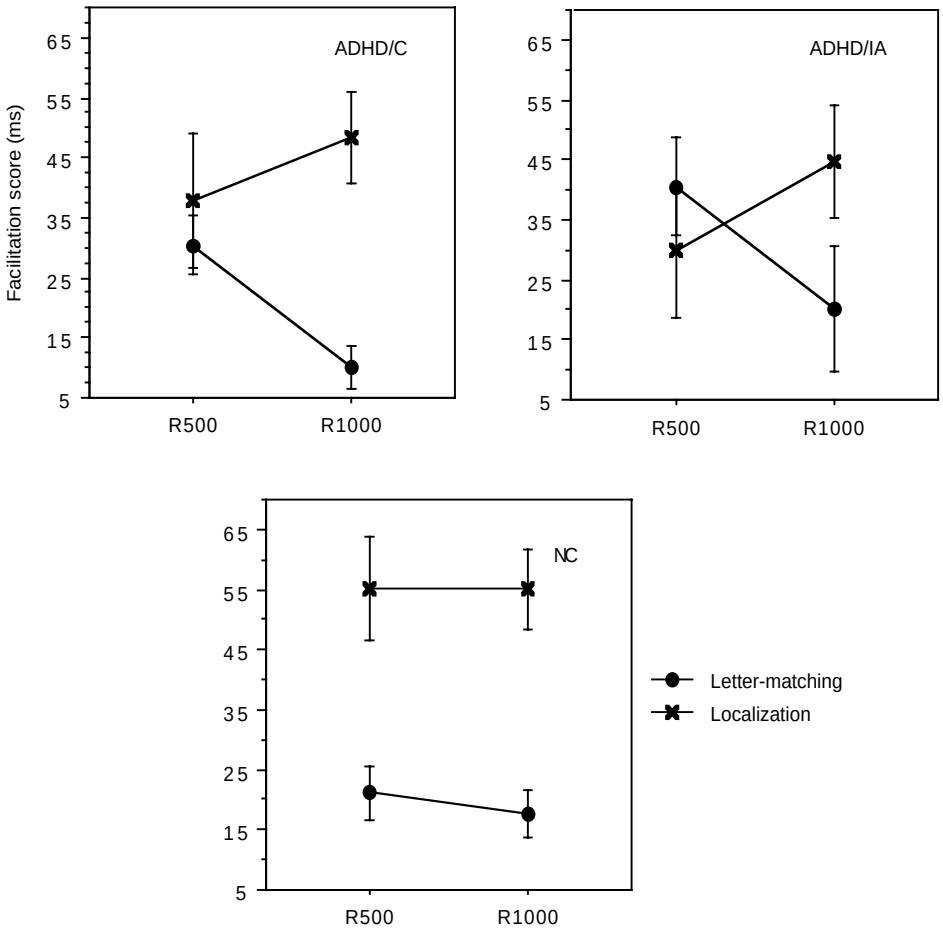

Figure 4.1: Facilitation in the letter-matching and localization tasks for each group

4.2 Implications for processes of selective attention

4.2.1 Inhibition

The efficiency of inhibitory processes can be examined by looking at not only the magnitude of negative priming but also its time course. As shown in the profiles of the NC group, the level of inhibition that remained stable as a function of RSI might be of optimal efficiency. Along this line, the greater magnitude of negative priming in the ADHD/IA group compared to the NC group suggests that the ADHD/IA group might be inhibiting distractor information more than is necessary during the task, leading to slower RTs on NP trials than the NC group (without any increase in accuracy). As suggested in the literature on the relationship between absorption and the magnitude of NP (see 2.3.4), overactive inhibition can be an indication of an inefficient inhibitory process. In addition, the inability of the ADHD/IA group to inhibit distractor information for as long as the NC group may be another indication of inefficient inhibitory processes in this group.

On the other hand, the inhibitory processes in the ADHD/C group appear to be intact since profiles of negative priming in this group are similar to those of the NC group. However, the greater NP at 1000ms compared to the NC group (d = .44) raises the possibility that inhibition is overactive in the ADHD/C group, similar to the ADHD/IA group, although the time course in these two groups showed different patterns.

4.2.2 Facilitation

Despite distinct profiles of negative priming in the two ADHD subtypes, their profiles of facilitation are similar to each other, but distinct from those in the NC group across two different tasks. It is beyond the scope of this study to interpret at what stage of time course of facilitation was measured with the NC

group given that there were only two RSIs used and the magnitude of facilitation in the NC group did not change significantly as a function of RSI. Nevertheless, it seems reasonable to speculate that being sensitive even to the brief lapse of time (over 500ms) as shown in both ADHD subtypes might pose challenges to processing targets consistently. Alternatively, facilitation processes in the two ADHD subtypes might not be as stable as those in the NC group.

4.3 Implications for theories of ADHD

The finding that the time course of negative priming differentiated the ADHD/IA group from both the ADHD/C and NC groups seems to support Nigg's (2001) notion that the ADHD/IA type may have deficits in cognitive inhibition. In addition, the finding that the ADHD/IA type showed different profiles both in inhibition and facilitation seems to support Barkley's (1997) notion that the core deficits in the ADHD/IA type are in selective attention.

The finding that the ADHD/C type showed similar profiles of negative priming to the NC group is in line with other negative priming studies in adults with ADHD (Armstrong et al., 2001; Nigg et al., 2002). It should be noted, however, that study findings are not directly comparable because of differences in tasks and sample characteristics. The intact negative priming in the ADHD/C group differed, however, from two negative priming studies of ADHD using a similar letter-matching task (Marriott, 1998; Ozonoff & Strayer, 1998). However, both studies used children with ADHD as participants. Further, the focus of Ozonoff and Strayer study (1998) was on children with Tourettes Syndrome (TS) and negative priming was reported only on children with ADHD+TS/OCD. The screening process in another study (Marriott, 1998) was based on rating scales, not DSM-IV criteria. Nevertheless, further research is

needed to investigate if discrepant findings reflect maturation of cognitive inhibition. The ADHD/C type seems to have difficulty with the facilitation process of selective attention but not with the inhibitory process. This might explain previous mixed findings about whether this group has a selective attention deficit. It is noteworthy that studies using selective attention tasks did not examine inhibition and facilitation separately as in the current study, and thus were not able to specify deficits. Whether the deficit in the facilitation process of selective attention in the ADHD/C group is secondary to inattention or behavior inhibition deficits is beyond the scope of the study.

In sum, this study successfully differentiated the two subtypes of ADHD not only from the NC group but also from each other by tracking the time course of facilitation and inhibition in selective attention. Profiles of selective attention in the ADHD/IA type suggest that this group has a deficiency in inhibition as indicated by over-inhibition that is short-lived and a possible deficiency in facilitation as evidenced by a slow time course. The ADHD/C group seems to have intact inhibition, but problematic facilitation. Study findings highlight the importance of assessing the time course of negative priming effects and the effect of different task parameters.

4.4 Limitations

Despite the implications about the validity of ADHD subtypes, this study has limitations: 1) Because the time course was based on only two time points, the full course of buildup and decay were not tracked. 2) Findings in this study might only reflect a limited range of pathology associated with ADHD since participants who showed extreme RT patterns were excluded from ANOVAs. Relatedly, constraints that reaction time tasks put on the data set for

common data analyses (e.g. ANOVA) might be problematic for studying clinical populations, which often show great variability, making data collection more time consuming and costly. 3) The small number of participants with comorbid CD makes it hard to examine the potential contribution of comorbity to heterogeneity within the subtypes. 4) Only male students were used and thus findings cannot be generalized to females. 5) Negative priming tasks are considered to tap relatively automatic process of inhibition, so whether these two subtypes have distinct profiles in tasks tapping more effortful aspect of cognitive inhibition (e.g. as reflected in a directed forgetting task) still needs further research. 6) The absence of negative priming effects across all groups in the localization task limits conclusions about subtype differences in selective attention to the letter-matching task. 7) The study was based on the inhibitory account of negative priming and did not rule out other processes that might underlie negative priming effects.

4.5 Future directions

For future research, using more RSIs will provide a fuller picture of the time course of selective attention although adding more RSI requires more sessions, making the study more time-consuming and costly. The use of multiple negative priming tasks will provide information about the generality of differential deficits in cognitive inhibition. In addition, comparing the performance of ADHD subtypes on measures tapping automatic vs. effortful cognitive inhibition (automatic vs. effortful) will further understanding of the scope of cognitive inhibition deficit in the ADHD/IA type.

Drawing a large sample for subgroup analyses might further clarify the nature of inattention in the ADHD subtypes. The use of psychiatric control groups will shed light on the specificity of deficits in selective attention

associated with ADHD. Comparing the performance of the ADHD subtypes on measures of behavioral inhibition (e.g. the Stop Signal task) as well as cognitive inhibition will help establish the primacy of deficits (behavioral vs. cognitive) in each subtype.

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