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A Comparison of the Neuropsychological Profiles of the *DSM-IV* Subtypes of ADHD

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Recent research on the *DSM-IV* subtypes of attention-deficit/hyperactivity disorder (ADHD) has demonstrated that the subtypes differ in demographic characteristics, types of functional impairment, and profiles of comorbidity with other childhood disorders. However, little research has tested whether the subtypes differ in underlying neuropsychological deficits. This study compared the neuropsychological profiles of children without ADHD ($n = 82$) and children who met symptom criteria for *DSM-IV* Predominantly Inattentive subtype (ADHD-IA; $n = 67$), Predominantly Hyperactive Impulsive subtype (ADHD-HI; $n = 14$), and Combined subtype (ADHD-C; $n = 33$) in the areas of processing speed, vigilance, and inhibition. We hypothesized that children with elevations of inattention symptoms (ADHD-IA and ADHD-C) would be impaired on measures of vigilance and processing speed, whereas children with significant hyperactivity/impulsivity (ADHD-HI and ADHD-C) would be impaired on measures of inhibition. Contrary to prediction, symptoms of inattention best predicted performance on all dependent measures, and ADHD-IA and ADHD-C children had similar profiles of impairment. In contrast, children with ADHD-HI were not significantly impaired on any dependent measures once subclinical symptoms of inattention were controlled. Our results do not support distinct neuropsychological deficits in ADHD-IA and ADHD-C children, and suggest that symptoms of inattention, rather than symptoms of hyperactivity/impulsivity, are associated with neuropsychological impairment.

KEY WORDS: attention-deficit/hyperactivity disorder; neuropsychology; *DSM-IV*; subtypes.

INTRODUCTION

Attention-deficit/hyperactivity disorder (ADHD) is currently one of the most common disorders of childhood, occurring in 3–5% of children (American Psychiatric Association (APA), 1994). The defining symptoms of ADHD include high levels of activity, impulsivity, and inattention, and can lead to difficulties in scholastic, social, and family contexts. More boys are diagnosed with this disorder than are girls, with male to female ratios ranging from 3:1 to 9:1 (Lahey et al., 1994; Sandberg, 1996).

There have been substantial changes to the diagnostic construct of ADHD over the years. Currently, the *Diagnostic and Statistical Manual of Mental Disorders-IV* (*DSM-IV*; APA, 1994) defines ADHD based on elevations of two separate but correlated symptom dimensions, those of inattention (IA) and hyperactivity/impulsivity (H/I). Children meet criteria for the disorder by having six or more symptoms of either IA or of H/I, or both. Hence, *DSM-IV* describes three diagnostic subtypes of ADHD based on differential elevations of symptoms on these two dimensions. The first is Predominantly Inattentive subtype (ADHD-IA), in which children have six or more symptoms of IA but fewer than six symptoms of H/I, the second is Predominantly Hyperactive/Impulsive subtype (ADHD-HI), in which children have six or more symptoms of H/I but fewer than six symptoms of IA, and the third is Combined subtype (ADHD-C), in which children show elevations of six or more symptoms on both dimensions. The *DSM-IV* field trials indicated that the current subtypes differ significantly on variables such as age of onset, gender ratio, and level of social and academic

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impairment (Lahey et al., 1994). Recent research also suggests that the subtypes may differ in rates of comorbidity with other childhood disorders (Eiraldi, Power, & Nezu, 1997; Faraone, Biederman, Weber, & Russell, 1998; Willcutt, Pennington, Chhabildas, Friedman, & Alexander, 1999). However, it is unclear whether the *DSM-IV* subtypes of ADHD differ neuropsychologically. A finding of differential neuropsychological profiles would not only lend external validity to the subtypes, but could suggest that the different subtypes develop along different etiologic pathways, may require varying treatments, and may have differential outcomes.

The Neuropsychology of ADHD

Although more work is needed to understand the neuropsychological correlates of the ADHD subtypes, we do know a fair amount about the neuropsychological correlates of ADHD as a global category. Tests that tap neurocognitive domains such as vigilance, sustained attention, and executive function (EF) have been useful in distinguishing those with ADHD from controls. Children with ADHD fairly consistently exhibit poorer performance on measures of EF, vigilance, and perceptual speed, but usually perform within normal limits on a variety of verbal or spatial measures (Barkley, 1997; Pennington & Ozonoff, 1996). Within the EF domain, tests of motor inhibition such as Continuous Performance Tasks and the Stop Task are especially sensitive measures of ADHD (Pennington & Ozonoff, 1996). In a recent meta-analysis of studies using the Stop Task (Oosterlaan & Sergeant, 1998), consistent deficits were demonstrated in groups with ADHD, providing evidence that children with ADHD are impaired in their ability to inhibit. Moreover, this deficit has not been found to be explainable by IQ, comorbid disorders, or reading disability, suggesting that it may be specific to ADHD (Nigg, 1999; Oosterlaan & Sergeant, 1998).

Studies of neuropsychological function in ADHD that have used previous subtype distinctions have obtained mixed results. The third edition of the *Diagnostic and Statistical Manual of Mental Disorders* (*DSM-III*; APA, 1980) defined two subtypes of ADHD; ADD with hyperactivity and ADD without hyperactivity. Arguably, these two previous subtypes are somewhat comparable to the current ADHD-C and ADHD-IA subtypes, respectively (McBurnett et al., 1999). A review by Carlson (1986) demonstrated that children with the *DSM-III* subtypes of ADD with hyperactivity and ADD without hyperactivity both showed deficits on neuropsychological tests compared to controls, and there were few differences between these subtypes. Other studies using clinical samples have also found few differences between these groups on cognitive measures (Hynd et al., 1989; Schaughency, Lahey, Hynd, Stone, & Piacentini, 1989). In contrast, in a school-based study, Sergeant and Scholten (1985) found children with ADD with hyperactivity to be significantly slower and less accurate than controls, whereas children without hyperactivity differed from controls only in showing a slower search rate. Barkley, DuPaul, and McMurray (1990) also found significant differences between these groups on cognitive measures using a clinical sample. Children without hyperactivity were found to have deficits in timed perceptual-motor tasks, but did not exhibit deficits in impulsivity or sustained attention on a vigilance task. Those with hyperactivity exhibited no deficits on the timed perceptual-motor tasks, but exhibited impulsive responding and difficulty in sustained attention. These findings by Barkley et al. (1990) and Sergeant and Scholten (1985) suggest that differential deficits in processing speed and inhibition may discriminate between the previous *DSM-III* subtypes.

To date, there have been relatively few studies regarding the neuropsychological performance of children with the current *DSM-IV* subtypes, and those that have been conducted have obtained inconsistent results. Houghton et al. (1999) found that although ADHD-IA and ADHD-C children were significantly different from controls on measures of inhibition, planning, and set-shifting, the two subtypes were not significantly different from one another (although only the combined type differed from controls in perseveration and response inhibition). In contrast, utilizing a combined clinical and community sample, Nigg, Blaskey, Huang-Pollack, and Rappley (under review) found that boys with ADHD-C exhibited deficits in behavioral inhibition relative to boys with ADHD-IA. Girls in both of these subtypes, however, had similar deficits on the inhibition measure. Both subtypes also exhibited deficits in processing speed in this study. Finally, in a clinic-based study, Klorman et al. (1999) found that children with ADHD-C achieved fewer correct solutions and made more rule violations than children without ADHD on the Tower of Hanoi, a measure of planning, whereas children with ADHD-IA were not significantly different from the comparison sample.

Clearly, more research is needed to determine whether the *DSM-IV* subtypes of ADHD are associated with differential neuropsychological impairments. Based on the two symptom dimensions that define the *DSM-IV* subtypes, one can construct several competing hypotheses regarding neuropsychological performance of the subtypes. We will present our hypotheses first based on the dimensions of IA and H/I, and will then extend the logic from this dimensional framework to parallel hypotheses regarding performance of children with the categorical subtypes. In addition, we will briefly summarize some of the other hypotheses that could be posed.

Hypotheses

It is possible that the dimensions of IA and H/I are each associated with unique neuropsychological impairments. For instance, as Barkley (1997) proposes and some previous studies of *DSM-III* ADHD support, the dimension of H/I may be associated with deficits in behavioral inhibition. In contrast, some studies suggest that the dimension of IA may be associated with general deficits in processing speed and vigilance. When extended to the *DSM-IV* subtypes, we predict that children with ADHD-IA will be impaired on measures of processing speed and vigilance, and will *not* be impaired on measures tapping inhibition. We predict that children with ADHD-HI will be impaired only on inhibition measures, but not on those assessing vigilance or processing speed. Children with the ADHD-C subtype, because it shares elevations on both dimensions, are predicted to exhibit deficits on processing speed, vigilance, and inhibition measures. Additionally, these deficits could be more severe than the deficits exhibited by children with the other two subtypes, as the interaction between these two dimensions could cause more severe impairment.

Although there is some evidence in support of this hypothesis, these are not the only predictions that could be made regarding the neuropsychological deficits associated with the *DSM-IV* subtypes. Because the symptom dimensions are highly correlated ($r = .57$, $p < .0001$ in our sample), it is possible that both the dimension of IA and the dimension of H/I are associated with the same underlying deficits. For instance, because behavioral inhibition is the most robust deficit found in children with the overall diagnosis of ADHD, it is possible that both symptom dimensions are associated with deficits in behavioral inhibition. Another possibility is that only one of the two dimensions is actually associated with significant neuropsychological impairment. Again, because the two symptom dimensions are so highly correlated, one symptom dimension could be associated with underlying neuropsychological impairment, whereas the other dimension may simply be indexing symptoms that are highly correlated with the deficits associated with the first dimension. For instance, if the dimension of IA is associated with neuropsychological impairment, then only children with the ADHD-IA and ADHD-C subtypes would be significantly impaired on neuropsychological measures. In contrast, if the dimension of H/I drives the neuropsychological deficits, then only children with the ADHD-HI and ADHD-C subtypes would be impaired on these measures.

The Present Study

In sum, the goal of this study was to examine the neuropsychological profiles of children in a community sample, using both dimensional and categorical approaches. The dimensional approach involved regression analyses that examined associations between the number of inattention and hyperactivity/impulsivity symptoms and test performance, whereas the categorical approach entailed group comparisons of the *DSM-IV* subtypes and controls. Children completed a battery of neuropsychological tests in the areas of processing speed, vigilance, and inhibition. Although the ADHD groups were not formally diagnosed, they had six or more symptoms of either IA or H/I, or both, on a *DSM-IV* checklist (Barkley & Murphy, 1998; DuPaul et al., 1997; Lahey et al., 1998) that explicitly lists the *DSM-IV* criteria for the disorder.

We hypothesized that the dimension of IA would best predict impairment on measures of vigilance and processing speed, whereas the H/I dimension would best predict impairment on measures of inhibition. Therefore, the *DSM-IV* subtypes were predicted to differ on these measures as well, with ADHD-IA children having only deficits on processing speed and vigilance, ADHD-HI children having only deficits in inhibition, and children with the ADHD-C subtype exhibiting deficits on all measures.

METHOD

Participants

This study was part of the ongoing Colorado Learning Disabilities Research Center twin project that examines ADHD, Reading Disability, and comorbid disorders (DeFries et al., 1997). As part of the larger study, parents of all twin pairs in 35 local school districts were contacted and invited to participate in the study. As part of the screening procedures for the study, parents and teachers of each twin were asked to complete a brief behavioral questionnaire that included an assessment of all *DSM-IV* symptoms of ADHD. For this study, twin pairs, ages 8–18, were ascertained in which at least one twin met ADHD criteria according to parent or teacher report. In addition, control twins in which neither child met criteria for ADHD were recruited. Approximately 40% of the families who were contacted agreed to participate in this initial screening procedure, and 87% of the families in the screening

Table I. Description of the Sample

	ADHD-IA ($n = 67$)	ADHD-HI ($n = 14$)	ADHD-C ($n = 33$)	Controls ($n = 82$)
Age	12.00 (3.01)$_a$	10.32 (1.78)$_b$	10.87 (2.07)$_b$	11.40 (2.48)$_{a,b}$
Gender (M:F)	2.05 : 1$_a$	2.5 : 1$_a$	2.67 : 1$_a$	1 : 1.41$_b$
Full Scale IQ	97.97 (11.92)$_a$	113.36 (10.36)$_b$	98.94 (8.99)$_a$	114.71 (12.24)$_b$
Verbal IQ	98.15 (13.34)$_a$	113.36 (10.43)$_b$	98.42 (10.19)$_a$	113.80 (12.44)$_b$
Performance IQ	98.70 (12.04)$_a$	110.29 (11.21)$_b$	100.15 (12.13)$_a$	112.77 (13.02)$_b$
Inattention symptoms[a]	7.64 (1.21)$_a$	3.14 (1.66)$_b$	8.24 (.90)$_c$	.76 (1.42)$_d$
Hyperactive/Impulsivity symptoms[a]	1.93 (1.68)$_a$	6.93 (1.14)$_b$	7.61 (1.17)$_b$	.44 (1.00)$_c$
Reading composite[b]	−.37(1.23)$_a$	.81 (1.08)$_b$	−.59 (1.25)$_a$	1.48 (1.10)$_c$

Note. Values with different subscripts are significantly different from one another ($p < .05$).
[a]Symptom counts are based on the combination of parent and teacher report on the *DSM-IV* checklist. This checklist is rated on a 0–3 scale, with items receiving endorsements of 2 or 3 scored as positive symptoms.
[b]Reading Composite is a measure of reading ability based on the Reading Recognition, Reading Comprehension, and Spelling subtests of the PIAT. Lower numbers indicate greater levels of reading difficulty.

sample agreed to participate in the larger study. Although the rate of participation was slightly higher among control twin pairs (91%) than twin pairs in which at least one twin met symptom criteria for ADHD (84%), this difference was not significant. This school-based sampling procedure sought to avoid the overselection of individuals with extreme symptomatology, such as those often encountered in clinically ascertained research samples (Berkson, 1946). However, there were still expected to be more males than females in the sample due to the higher rate of ADHD in males (Sandberg, 1996).

The descriptive characteristics of the sample are provided in Table I. Our sample consisted of 82 control children, 67 children with ADHD-IA, 14 children with ADHD-HI, and 33 children with ADHD-C. In any case in which both children from a twin pair met criteria for ADHD, one twin was selected randomly for use in the analyses. We also randomly selected one twin from each pair in the comparison sample, so that we never used both twins from a twin pair in the analyses. The groups did not differ in socioeconomic status or ethnicity; the ethnic composition of the overall sample was approximately 85% White, 8% Hispanic, 4% Black, 2% Asian, and 1% American Indian. Males outnumbered females in all ADHD subtypes in this sample, and the subtypes did not differ significantly in gender ratio. The control group consisted of more females than males, with a male to female ratio of 1:1.41. Children with ADHD-IA were significantly older than all other ADHD subtypes, but did not differ significantly from controls with regard to age. Both children with ADHD-IA and ADHD-C differed significantly from controls on Full-Scale IQ, Performance IQ, Verbal IQ, and reading composite score. Children with ADHD-HI did not differ significantly from controls on any IQ measure. The reading composite score for the ADHD-HI children was significantly lower than that of controls; however, it was also significantly higher than those of the other two ADHD subtypes.

Procedures

Prior to their entrance into the study, parents and teachers of twins were asked to complete a *DSM-IV Checklist*, a brief questionnaire that assesses symptoms of *DSM-IV* ADHD. Parent and teacher ratings of ADHD symptoms were then combined using the “or-rule,” which codes each ADHD symptom as positive if it is endorsed by either the parent or the teacher (Piacentini, Cohen, & Cohen, 1992). This procedure was utilized to determine ADHD status in the *DSM-IV* field trials (Lahey et al., 1994).

Initial telephone interviews were conducted by staff at the University of Colorado Institute for Behavioral Genetics (IBG). Because the focus of this research is on familial ADHD and its correlates, participants with known environmental brain insults or other rare etiologies that may produce the symptoms of ADHD, such as pervasive developmental disorder or exposure to lead, were eliminated from the study.

After informed consent had been obtained from all parents and twins, each pair of twins completed a detailed psychoeducational battery at IBG. This test battery assessed general cognitive ability and specific learning difficulties, both of which may influence the phenotypic manifestation of ADHD (Pennington, Grossier, & Welsh, 1993). About 1 month after the testing at IBG, twins and their parents attended a second session of testing at the University of Denver Department of Psychology. Here graduate students administered a series of neuropsychological and psychopathology measures to the twins. Any twins taking stimulant medication discontinued medication 24 hr prior to participation in the testing.

MEASURES

Diagnostic and Descriptive Measures

A *DSM-IV Checklist* similar to measures used in other studies of *DSM-IV* ADHD (e.g., Barkley & Murphy, 1998; DuPaul et al., 1997; Lahey et al., 1998) was utilized to obtain both parent and teacher ratings of symptoms of ADHD. Each symptom on this checklist is identical to the symptom listed in *DSM-IV*'s criteria for the disorder. Parents and teachers are instructed to circle the number next to each question that best describes the child (i.e., 0 – *not at all*, 1 – *just a little*, 2 – *pretty much*, 3 – *very much*). Items that were endorsed as 2 or 3 were scored as positive symptoms of ADHD. As mentioned previously, any symptom that was endorsed by either parent or teacher was counted as a positive symptom for the diagnosis. Children with six or more symptoms of either IA or H/I, or both, were recruited for the study as ADHD participants.

The *Peabody Individual Achievement Test* (PIAT; Dunn & Markwardt, 1970) was utilized to assess academic achievement in reading and spelling. To obtain a measure of overall reading ability, a discriminant function analysis was conducted on a separate non-twin sample of individuals with and without a school history of reading problems (DeFries, 1985). This analysis produced a normally distributed, weighted composite score based on the Reading Recognition, Reading Comprehension, and Spelling subtests of the PIAT that best predicted a school history of reading difficulty.

The *Wechsler Intelligence Scale for Children* (WISC-R; Wechsler, 1974) was utilized to assess the Full-Scale IQ (FSIQ) of participants 16 years of age or younger, and the *Wechsler Adult Intelligence Scale* (WAIS-R, Wechsler, 1981) was utilized for participants who were 17 or 18 years of age.

Neuropsychological Measures

We selected neuropsychological measures that would allow us to test specific predictions regarding differential impairment of the symptom dimensions of IA and H/I and the *DSM-IV* subtypes. Therefore our measures fit into three general domains: inhibition, vigilance, and processing speed.

Inhibition Measures

The *Gordon Diagnostic System* (GDS; Gordon & Mettelman, 1988) is one type of Continuous Performance Task (CPT; Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956). For the Vigilance subtest the participant must press a specified button only in response to a correct series of two digits. The Distractibility subtest is similar, but contains more sources of distraction, as numbers are flashing in three columns instead of only one. For this part, the participant is told to attend only to the center column and ignore the other two columns. For both subtests there are 540 trials, each presented 1 s apart, with 45 of these trials serving as target stimuli. Errors of commission are utilized as the dependent measure for the inhibition domain. Because subjects may also make omission errors, this task also measures vigilance, as discussed later.

The *Stop Task* (Logan, Cowan, & Davis, 1984) is a computerized measure of inhibitory control that was developed based on the dual-process "race model" of inhibition proposed by Logan and colleagues (e.g., Logan, 1994; Logan, Schachar, & Tannock, 1997). On primary task trials, the letter X or O is presented in the center of the monitor, and the participant responds by pressing the corresponding key on the keyboard. For stop-signal trials the same visual stimulus appears, but an auditory tone is also presented shortly after the X or the O appears on the screen. The participant is instructed to press the X or O key as rapidly as possible for each trial, but to inhibit the key press on each of the trials on which the tone is presented. The task utilizes a tracking procedure in which stop-signal delay changes after every trial with a stop signal (e.g., Logan et al., 1997). By increasing the stop-signal delay by 50 ms if the participant is able to inhibit and decreasing the delay by 50 ms if the participant responds, this procedure converges on the stop-signal delay at which the participant responds on 50% of the trials. Stop-signal reaction time (SSRT), an experimental measure of how long it takes a participant to inhibit a response, is then estimated by subtracting this stop-signal delay from the mean reaction time on the primary task trials, and was used as the dependent variable for this measure.

Processing Speed Measures

The *Trialmaking Test* (Reitan & Wolfson, 1985) consists of two separate parts, A and B. Part A of this test requires the participant to use a pencil to connect in ascending order a series of circles containing numbers. Part B also involves connecting circles, but this time each circle contains either a number or a letter. The participant is instructed to connect the circles in ascending order, alternating between numbers and letters (e.g., 1-A, 2-B, 3-C, etc.). Therefore this task requires the individual to maintain his/her place in both the alphabetical and numerical series while also remembering whether a number or letter should be next in the series. The dependent measure is the time it takes the participant to complete each task.

The *Coding Subtest from the WISC-R* (WISC-R; Wechsler, 1974) is a brief, standardized task that requires the participant to copy symbols associated with particular digits. A key is given at the top of the page that designates the symbol associated with each digit, and below this are a series of digits that are missing the designated symbols. The individual does not need to remember this code (as they can reference it during the task) but simply needs to fill in the appropriate symbol below each digit. According to the WISC-III (Wechsler, 1991), this task indexes mainly processing speed and loads on a processing speed factor. The dependent measure is the total number correct after 2 min.

Vigilance Measure

The *GDS* is also used as a measure of vigilance. Errors of omission, which may index a lack of sustained attention, are utilized as the dependent measure of Vigilance for this study.

ANALYSES

Composite scores were utilized when appropriate in order to reduce the number of comparisons. Because the correlation between omission errors across subtests of the GDS was highly significant ($r = .65$, $p < .0001$), omission errors were summed across both subtests of the GDS. Similarly, commission errors were summed across both of these subtests ($r = .78$, $p < .0001$). Therefore the one vigilance measure was GDS Total Omissions, whereas one of the two Inhibition measures consisted of GDS Total Commissions. In addition, times for Trails Part A and Part B were summed to create one variable for analysis, Trails Total Time. The pattern of results was identical for both Part A and Part B of this task.

Prior to any inferential statistics, all dependent variables were examined for deviations from the required assumptions (e.g., normality), and transformations were made when necessary. Variables log-transformed included SSRT, GDS commission and omission errors, and Trails Total Time.

We first conducted a series of multiple regression analyses to test whether symptoms of IA, symptoms of H/I, or the interaction between the two dimensions best predicted performance on each of the dependent measures. Although these symptom dimensions are highly correlated ($r = .57$ in our sample), they still share only about 32% of the total variance in the symptom dimensions and therefore each could still contribute uniquely to task performance. A priori hypotheses were that the vigilance and processing speed measures (GDS omissions, Coding scaled score, and Trails Total Time) would be best predicted by symptoms of IA, whereas performance on the inhibition measures would be best predicted by symptoms of H/I (GDS Commissions and SSRT). We initially conducted stepwise regressions with symptoms of IA, symptoms of H/I, and the interaction between the two domains as the independent variables predicting each dependent measure. After this, we conducted each stepwise regression analysis including Full-Scale IQ, reading composite score, age, and gender as independent variables (along with the symptom dimensions) to see if any of the symptom dimensions still predicted neuropsychological performance when these variables were also introduced into the model.

In addition to these dimensional analyses, we also conducted categorical analyses to determine whether the *DSM-IV* subtypes differed on the dependent variables of interest. Within the Inhibition and Processing Speed Domains, the first analyses conducted were Repeated Measures mixed model MANCOVA's with group (Control, ADHD-IA, ADHD-HI, and ADHD-C) as the between-subjects variable and task as the within-subjects variable. Because we had a priori predictions regarding how the subtypes would differ on each measure, if this overall test showed a significant group effect we conducted planned post hoc tests among the groups. All post hoc tests were conducted as planned comparisons based on our hypotheses, so no alpha correction was utilized. Because there was only one measure in the Vigilance domain, only a univariate ANCOVA and post hoc test was necessary in this area. For any neuropsychological measures that differed significantly among the four groups, we also extended the dimensional approach by conducting follow-up analyses to test which symptom dimension was driving the neuropsychological deficit for each subtype. Specifically, because the ADHD-HI group exhibited significant subclinical elevations of IA and the ADHD-IA group exhibited significant subclinical elevations of H/I symptoms, we tested whether obtained deficits were associated specifically with the primary symptom dimension associated with the subtype or were explained by subclinical elevations on the other symptom dimension.

Consistent with other studies of the *DSM-IV* ADHD subtypes (e.g., Lahey et al., 1994; McBurnett et al., 1999), the mean age of the ADHD-IA subtype in our sample was significantly older at the time of assessment than the age of the other two ADHD subtypes, and all three ADHD subtypes had a larger proportion of males than the comparison sample. In addition, our sample consisted of children from a large age range. Therefore, we felt it was important to determine whether any group differences varied by age or gender. In our preliminary categorical analyses, we conducted Group × Age and Group × Gender interactions. Because none of these interactions was significant in any of the neuropsychological domains, it was not necessary to complete follow-up analyses regarding age and gender. However, because there were significant group differences on these variables, we used both age and gender as covariates in all categorical analyses.

The fact that the ADHD-IA and ADHD-C groups scored significantly lower than children without ADHD on measures of IQ and reading achievement presents a methodological dilemma. Specifically, some authors (e.g., Werry, Elkind, & Reeves, 1987) have argued that these measures should be included as covariates in all analyses to ensure that deficits associated with ADHD cannot be explained more parsimoniously by group differences in intelligence or academic achievement. In contrast, others (e.g., Barkley, 1997) suggest that ADHD may directly cause mild IQ or achievement deficits in comparison to individuals without ADHD, and that controlling for these variables therefore removes a portion of the variance that is associated specifically with ADHD. Because this issue has not been resolved conclusively, we conducted all analyses with and without controlling reading achievement and IQ. If these results differed we describe both analyses in the text, whereas if the pattern of results was the same we describe only the findings of the most conservative model including all covariates.

It is also important to note that the number of participants in each group could limit the power to detect significant group differences. Previous studies have found moderate to large effect sizes on inhibition measures in ADHD (Pennington & Ozonoff, 1996) compared to age- and IQ-matched controls. Smaller effect sizes would be expected in this study, however, because groups with ADHD are being compared to one another. Given a medium effect size (Cohen's $d = .35$), with 100 total participants and alpha set at .05, power is estimated to be .90 (Borenstein & Cohen, 1988). Therefore, analyses were judged to have significant power to detect differences between the ADHD-IA and ADHD-C subtypes. However, the ADHD-HI subtype only consisted of 14 children, and this may not provide sufficient power to reliably determine whether this subtype differs from the other groups. Therefore, post hoc tests involving the ADHD-HI subtype should be considered exploratory.

RESULTS

Dimensional Analyses

For the dimensional regression analyses, separate stepwise linear regressions were used to predict each dependent measure (GDS Commissions, SSRT, Coding, Trails Total Time, and GDS Omissions) with symptoms of IA, symptoms of H/I, and the interaction between the two dimensions as the independent measures. Results were contrary to prediction, as every dependent measure was best predicted by symptoms of IA (See Table II). Symptoms of H/I and the interaction term were not significant in any of these linear regression models. Moreover, when including Full-Scale IQ, reading composite score, gender, and age in each of the models (See Table III), symptoms of IA was still one of the significant predictors of performance on every dependent measure, whereas symptoms of H/I was a significant predictor only for Trails Total Time (In this case, symptoms of H/I negatively predicted Trails performance, with higher levels of H/I predicting a faster processing speed).

Categorical Analyses

Inhibition

The two inhibition measures (GDS commission errors and SSRT) were first analyzed using a Repeated Measures mixed model MANCOVA with group as the between-subjects variable and task as the within-subjects variable. There was a significant group main effect with all covariates in the model, $F(3, 147) = 5.02$, $p = .002$, providing strong evidence of inhibition differences among the groups. In addition, the Group × Task interaction effect was significant, $F(3, 147) = 2.98$, $p = .03$, arising largely because the ADHD-IA subtype had the highest SSRT, whereas the ADHD-C subtype made the most

Table II. Stepwise Regressions Predicting Performance on Each Neuropsychological Measure From IA Symptoms, H/I Symptoms, and/or Interaction

Variable	Significant predictors(s)	t	p	R^2
GDS Commissions	IA symptoms	5.71	.0001	11.8
SSRT	IA symptoms	6.02	.0001	13.7
WISC Coding	IA symptoms	−10.67	.0001	29.1
Trails Total Time	IA symptoms	6.68	.0001	14.0
GDS Omissions	IA symptoms	7.22	.0001	17.2

Note. GDS – Gordon Diagnostic System; SSRT – Stop Signal Reaction Time; IA – inattention; H/I – hyperactivity/impulsivity.

Table III. Stepwise Regressions Predicting Performance on Each Neuropsychological Measure From IA Symptoms, H/I Symptoms, Interaction, as well as covariates[a]

Variable	Significant predictors(s)	t	p	R^2
GDS Commissions	1. Age	−9.11	.0001	18.8
	2. Reading score	−3.75	.0001	33.4
	3. IA symptoms	3.63	.0001	36.9
SSRT	1. IA symptoms	4.07	.0001	14.0
	2. Age	−4.96	.0001	22.0
	3. Reading score	−2.29	.02	23.8
WISC coding	1. IA symptoms	−4.50	.0001	29.1
	2. Full-scale IQ	7.50	.0001	37.4
	3. Gender	4.22	.0001	41.2
	4. Age	3.03	.003	43.1
Trails Total Time	1. Fill-scale IQ	−5.88	.0001	16.4
	2. Age	−8.43	.0001	33.2
	3. IA symptoms	4.09	.0001	35.6
	4. H/I symptoms	−2.62	.009	37.2
GDS Omissions	1. Full-scale IQ	−6.70	.0001	18.4
	2. Age	−9.35	.0001	39.7
	3. IA Symptoms	4.20	.0001	43.8

Note. GDS – Gordon Diagnostic System; SSRT – Stop Signal Reaction Time; IA – inattention; H/I – hyperactivity/impulsivity.
[a]Covariates entered into the model included age, gender, reading composite score, and full-scale IQ.

commission errors (Table IV). In addition, age and reading composite were significant covariates in the model ($p < .05$). Individual post hoc tests controlling age and gender revealed that the ADHD-C and ADHD-IA subtypes were impaired relative to control participants on both inhibition measures ($p < .05$), although the significant difference in SSRT between the ADHD-C group and the control group was eliminated when FSIQ and reading achievement were controlled ($p < .14$). Participants with the ADHD-HI subtype also made more commission errors than the control group ($p < .05$). Thus, all three ADHD subtypes showed some evidence of impairment in comparison to controls on the inhibition measures. To specify the nature of these effects further, two follow-up MANCOVAs were conducted with either Symptoms of IA or Symptoms of H/I included as an additional covariate in the model. When symptoms of inattention were included as a covariate, all group differences were eliminated, $F(3, 146) = 0.87$, $p = .46$, including the previously significant difference between the ADHD-HI subtype and controls on errors of commission ($p = .15$). Therefore, although the ADHD-HI group is putatively a subtype with elevations of H/I alone, these results suggest that even in this group the mild inhibition deficits are not associated independently with H/I symptoms, but are instead explained by subclinical elevations of inattention. In contrast, a Repeated Measures Mixed Model MANCOVA on the two inhibition measures with the addition of H/I symptoms as the fifth covariate still yielded a significant group main effect, $F(3, 146) = 3.88$, $p = .01$, and the difference between the ADHD-IA group and the comparison group remained significant, suggesting that inhibition deficits in the ADHD-IA subtype are not explained by subclinical elevations of H/I symptomatology. Hence, there is strong evidence across these analyses and the prior dimensional regression analyses that differences among the groups in terms of symptoms of IA (and not in H/I) account substantially for performance in the inhibition domain.

Processing Speed

With all covariates in the model, there was a significant main effect of group, $F(3, 180) = 5.66$, $p = .001$, and a significant Group × Task interaction, $F(3, 180) = 7.24$, $p = .001$, for the dependent measures of WISC Coding and Trails Total Time, providing evidence of differences in processing speed among the groups (Table IV). In addition, gender and FSIQ ($p < .05$) were significant covariates in the model. Means in Table IV reveal that the ADHD-HI subtype and the control participants performed very similarly on each of these tasks. Post hoc tests revealed that the ADHD-IA and ADHD-C

Table IV. Neuropsychological Variables

Measures	ADHD-IA ($n = 63$)	ADHD-HI ($n = 14$)	ADHD-C ($n = 33$)	Controls ($n = 82$)
Inhibition				
GDS Commissions	$19.81\ (27.12)_a$	$21.85\ (27.36)_a$	$26.76\ (41.28)_a$	$6.51\ (9.77)_b$
SSRT	$355.23\ (139.58)_a$	$322.63\ (178.23)_b$	$341.22\ (130.79)_{a,b}$	$257.79\ (85.05)_b$
Processing speed				
WISC Coding	$7.44\ (3.09)_a$	$11.07\ (2.73)_b$	$7.21\ (2.33)_a$	$11.05\ (2.45)_b$
Trails Total Tome	$80.28\ (27.29)_a$	$50.23\ (17.24)_b$	$67.34\ (22.51)_b$	$55.27\ (22.41)_b$
Vigilance				
GDS Omissions	$17.32\ (14.20)_a$	$11.00\ (8.27)_{a,b}$	$14.83\ (9.30)_{a,b}$	$6.72\ (6.87)_b$

Note. Values without common subscripts are significantly different from one another after covariation of gender, age, Full-Scale IQ, and reading composite score ($p < .05$). GDS – Gordon Diagnostic System; SSRT – Stop Signal Reaction Time.

subtypes were significantly impaired on both processing speed measures relative to control participants and ADHD-HI participants when gender and age were controlled, although the ADHD-C group was not significantly different from the control and ADHD-HI groups on the Trailmaking test when FSIQ and reading composite were also covaried. In addition, the ADHD-IA type was significantly more impaired than the ADHD-C type on the Trailmaking test when all covariates were included in the model ($p < .05$). Moreover, each of these group differences remained significant when symptoms of H/I were also controlled ($p < .05$), whereas there were no significant group differences on either measure when symptoms of IA were covaried. In combination with the multiple regression analyses described previously, these results provide converging evidence that deficits in processing speed are associated only with significant elevations of inattention, and that these deficits may be most pronounced among individuals with ADHD-IA.

Vigilance

A univariate ANCOVA was completed to compare the four groups on the single measure (GDS omission errors) of vigilance. There was a significant group main effect with all covariates in the model, $F(3, 176) = 3.23$, $p = .024$. Age and Full-scale IQ were significant covariates in the model ($p < .05$). Post hoc tests controlling age and gender revealed that the ADHD-IA and ADHD-C groups made significantly more omission errors than the comparison group ($p < .05$). However, only ADHD-IA children differed significantly from controls when reading achievement and FSIQ were added as covariates. Once again, this difference remained significant even when symptoms of H/I were controlled, but disappeared when symptoms of IA were covaried. No other significant group differences were obtained.

DISCUSSION

The overall goal of this study was to examine whether the dimensions of IA and H/I and subtypes of *DSM-IV* ADHD were associated with differential neuropsychological profiles. We predicted that the dimension of IA would be associated with deficits in processing speed and vigilance, whereas the dimension of H/I would be uniquely associated with deficits in inhibition. When extended to the *DSM-IV* subtypes, our predictions were that children with the ADHD-IA and ADHD-C subtypes would both be impaired on tasks of processing speed and vigilance, as they both share elevations in symptoms of IA. Children with the ADHD-HI and ADHD-C subtypes should both be impaired on measures on inhibition, as they both share elevations in symptoms of H/I. However, the ADHD-IA children should not be impaired on measures of inhibition, nor should the ADHD-HI children be impaired on measures of processing speed or vigilance.

Contrary to prediction, there was convergent evidence that symptoms of IA are strongly associated with performance on all of these measures. Dimensional regression analyses that predicted performance on each dependent measure demonstrated that symptoms of IA best predicted performance within the vigilance, processing speed, and inhibition domains. In contrast, symptoms of H/I never significantly predicted performance in any of these domains. Categorical analyses showed that the ADHD-IA subtype was impaired relative to controls on all dependent measures, including those in the inhibition domain. The ADHD-C subtype was impaired relative to controls on all measures prior to covariation of Full-scale IQ and reading score. After covariation of these variables, children with ADHD-C were impaired relative to controls on WISC Coding and GDS Errors of Commission. However, there was only one significant difference in performance between the ADHD-IA and ADHD-C subtypes (Trails Total Time), suggesting that these two subtypes had highly similar profiles. In contrast, the ADHD-HI subtype was only impaired relative to controls on one measure, GDS errors of commission. Moreover, the difference between the ADHD-HI subtype and controls on this measure was eliminated after accounting for group differences in symptoms of inattention, again yielding evidence that the IA dimension, and not the H/I dimension, is associated with significant neuropsychological impairment. These results were similar across different age ranges and across gender, as there were no significant Group $\times$ Age or Group $\times$ Gender interactions.

These results are most consistent with the competing hypothesis that only one symptom dimension is significantly associated with neuropsychological impairment. Our results suggest that symptoms of IA are associated with significant neuropsychological deficits, whereas symptoms of H/I alone are not. Moreover, these results do not provide support for the discriminant validity of ADHD-IA and ADHD-C at the neuropsychological level. One possible explanation for the failure to find significant differences between the inattentive and combined subtypes may be the symptoms used to define the subtypes. The *DSM-IV* IA symptoms correlate highly with the *DSM-IV* H/I symptoms in our sample ($r = .57$) and others, and many of the IA symptoms describe behaviors that may arguably reflect inhibitory deficits (e.g., commits careless mistakes, fails to finish schoolwork). Therefore, it is possible that the *DSM-IV* IA and H/I symptoms may tap different facets of a latent trait that could be called "disinhibition." IA symptoms may primarily index cognitive aspects of disinhibition, whereas H/I symptoms may index more behavioral aspects of this trait. In addition to our present results, this model receives support from studies suggesting that ADHD-C and ADHD-IA children show similar impairment on measures of intelligence and academic achievement (e.g., Faraone et al., 1998; Lahey et al., 1998; Willcutt et al., 1999), whereas children with ADHD-C have higher rates of other disruptive disorders, aggressive behaviors, and peer rejection (Faraone et al., 1998; Maedgen & Carlson, 2000; McBurnett et al., 1999; Willcutt et al., 1999).

If *DSM-IV* IA symptoms in fact measure a latent trait characterized by disinhibition, these symptoms may not assess the attentional difficulties that are exhibited by children with a "true inattentive disorder" that is distinct from ADHD (e.g., Milich, Balantine, & Lynam, in press). Recent studies suggest that a separate cluster of symptoms describing "sluggish cognitive tempo" (Lahey et al., 1988; e.g., hypoactive, slow to respond, and easily confused) identify a meaningful subgroup within the ADHD-IA subtype that is associated with a distinct pattern of functional impairment and comorbid psychopathology (e.g., Carlson & Mann, under review; McBurnett, Pfiffner, & Frick, 2001). Because the current *DSM-IV* symptoms do not assess these behaviors, they may miss children with such an inattentive disorder that is not associated with deficits in inhibition.

Findings in this study also underscore the need for additional research on children with the ADHD-HI subtype. Previous studies suggest that children with the ADHD-HI subtype exhibit little or no impairment in intelligence, reading ability, or math ability, whereas children with the other two subtypes exhibit large deficits in each of these areas when compared to controls (Faraone et al., 1998; Lahey et al., 1998; McBurnett, et al., 1999; Willcutt et al., 1999). In addition, behavioral genetic analyses in our sample (Willcutt, Pennington, & DeFries, 2000) demonstrated that extreme scores on the H/I dimension were highly heritable only when the selected proband also exhibited a concurrent elevation of IA. The heritability of extreme H/I scores was nonsignificant and substantially lower when the proband did not exhibit significant elevations of IA, suggesting that H/I alone may not be indexing the same phenomenon as H/I paired with significant IA might. Hence, additional research is essential to test the nature and validity of the *DSM-IV* ADHD-HI subtype.

Finally, it should be noted that developmental changes in the manifestation of ADHD may have implications for our results and the results of other studies of the *DSM-IV* ADHD subtypes (e.g., McBurnett, 1997). Some researchers have suggested that many children with ADHD may follow a developmental pathway in which they meet criteria for ADHD-HI during the preschool years, ADHD-C as they are exposed to enough academic demands to begin to demonstrate significant IA, and ADHD-IA after symptoms of H/I decline during adolescence and adulthood (e.g., Barkley, 1997; Hart et al., 1995; Lahey et al., 1998). Based on this hypothesis, it is possible that much of our ADHD-IA sample consisted of children who would have met criteria for ADHD-C when they were younger, and whose symptoms of H/I had subsided at the time of participation in the study. This would be consistent with the significantly higher age of the ADHD-IA group, and it is possible that this could account for the observed deficits in inhibition within the ADHD-IA subtype.

LIMITATIONS AND DIRECTIONS FOR FUTURE RESEARCH

Limitations of this study include (a) the use of a twin sample, (b) sample size, and (c) age of the sample. However, although twins are generally 3–4 weeks premature, are lighter at birth, and develop language more slowly in early childhood, twins do not appear to be importantly different from singletons in the domain of psychopathology (Plomin, DeFries, McClearn, & Rutter, 1997). Further, the use of twins will facilitate future behavioral genetic analyses to test if common genes influence the *DSM-IV* subtypes and performance on neuropsychological measures. Nonetheless, future studies should also examine the neuropsychological correlates of the subtypes within singletons to test whether the current findings replicate in a nontwin sample.

The sample size in this study allowed sufficient power to test most of our hypotheses. However, there were very few ($n = 14$) children in the ADHD-HI subtype, which may have influenced the general lack of differences between this group and controls. Even so, one significant group difference was detected between the ADHD-HI subtype and controls, indicating that there was at least sufficient power to detect large effects. Additionally, the results of the dimensional analyses were highly consistent with the categorical comparisons. Moreover, children with the ADHD-HI subtype have been found to be less impaired than children with the other subtypes in other studies as well (e.g., McBurnett et al., 1999).

Another limitation is that the sample is composed mainly of older children. As discussed previously, it is possible that some of these children met criteria for the ADHD-IA subtype at the time of the study, but when younger may have met criteria for the ADHD-C subtype, and are thus not representative of a "pure inattentive subtype” that has exhibited only IA symptoms throughout development. Future studies should test if these results replicate in samples of children who have met criteria for the same subtype across development.

Strengths of the study include the use of a community sample, which avoids referral biases commonly found in clinic samples. The study also used multiple measures of the constructs of interest, such as more than one measure of inhibition. Future research should look more closely at the possible neuropsychological differences between the subtypes, using larger samples. This would allow more power to test for significant interactions of subtype with gender and age.

CONCLUSIONS

Children with ADHD-IA and ADHD-C had similar profiles of impairment across tasks assessing inhibition, processing speed, and vigilance. In contrast, children with ADHD-HI were not significantly impaired on any of these tasks once subclinical symptoms of IA were controlled. Our results do not support distinct neuropsychological deficits in ADHD-IA and ADHD-C children, and suggest that symptoms of IA, rather than symptoms of H/I are associated with neuropsychological impairment.

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