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Are There Executive Dysfunction Subtypes within Attention-Deficit/Hyperactivity Disorder?

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Abstract

Objective—Children with Attention-Deficit/Hyperactivity Disorder (ADHD) have heterogeneous behavioral and neuropsychological profiles. The aim of this study was to examine the possible utility of executive function (EF) subtypes within ADHD.

Methods—Participants were 357 children ages 6 through 13 with a diagnosis of ADHD. Children completed a brief laboratory battery measuring EF, including response inhibition, response variability, speed, and set-shifting. Children also completed standardized intelligence and achievement testing.

Results—Two-way cluster analysis of EF profiles of children with ADHD produced a three-cluster solution, labeled poor inhibitory control, poor set-shifting/speed, and intact task performance. Clusters significantly differed in measures of intelligence, academic achievement, and other disruptive behavior and anxiety/mood symptoms.

Conclusion—These findings further support the idea that children with ADHD have heterogeneous EF profiles and suggest that the theory of ADHD should consider these individual differences in EF profiles within the ADHD diagnostic category.

Attention-Deficit/Hyperactivity Disorder (ADHD) is a childhood disorder characterized by behavioral symptoms of inattention, hyperactivity, and impulsivity (APA, 2000). ADHD affects approximately 6% of children (Nigg 2006; Pastor & Reuben, 2002; Polanczyk, de Lima, Horta, Biederman, & Rohde, 2007) and is associated with a number of impairments including increased accidents, executive function deficits, language impairment, problems in interpersonal relationships, and academic underachievement (Barkley, 2006; Loe & Feldman, 2007). ADHD has been subdivided into three subtypes in DSM-IV-TR, based on symptom presentation: predominantly inattentive (i.e., defined as six or more inattentive ADHD symptoms), predominantly hyperactive-impulsive (i.e., defined as six or more hyperactive-impulsive symptoms), and a combined type (i.e., defined as six or more of both inattentive and hyperactive symptoms; APA, 2000). Unfortunately, these subtypes have not been well supported. For example, the subtypes are unstable over time such that children with one subtype early on are often diagnosed with a different subtype later during childhood (Lahey et al., 1994; 2005; Willcutt et al., 2012; but see Derefinko et al., 2008, Milich, 2001).

Another promising, but under examined, possible subtyping approach for ADHD might rely on Executive Function (EF) profiles. EF, “the ability to maintain an appropriate problem set for attainment of future goals” (Welsh & Pennington, 1988), has been touted as the primary deficit of children with ADHD and as such is a prominent feature of ADHD. Although ADHD has often been described as a disorder characterized by extensive EF impairments, not all children with ADHD exhibit these deficits (Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005). A literature review of the validity of this EF theory of ADHD suggests that, although EF impairment is an important aspect of ADHD for some individuals, EF impairment does not characterize all children with ADHD (Willcutt, Doyle, Nigg, Faraone & Pennington, 2005). Effect sizes of EF association with ADHD fall in only the medium range, also suggesting that either not all children with ADHD have EF deficits and/or that currently-used neuropsychological tests are not sensitive enough to detect all children’s deficits (Willcutt et al., 2005). Thus, children with ADHD may be able to be subtyped based on presence or relative absence of EF impairment, or based on profile of EF deficits.

The possibility of use of an EF impairment subtype or subtypes within ADHD has been proposed and has received some attention (Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005; Solanto et al. 2001; Sonuga-Barke, 2005; 2010). For example, Nigg, Willcutt, and colleagues (2005) proposed a simple 90th percentile cutoff as a starting point for evaluating children with ADHD with and without EF problems. This type of cutoff appeared to have some validity with regard to predicting other impairments. For example, children with EF problems typically exhibit worse academic achievement (Biederman et al., 2004; Bull, Espy, & Wiebe, 2008). Thus, further work on executive subtypes of ADHD is warranted since EF problems have real-world consequences for children with ADHD.

Yet, because EF is multicomponential (i.e., consists of several different components; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000), more than one type of EF profile may well exist within the broader ADHD diagnosis (Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005), in line with multiple pathway models of ADHD (e.g., Castellanos et al., 2006; Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005 ; Solanto et al. 2001; Sonuga-Barke, 2005; Sonuga-Barke et al., 2010). Since previous work suggests that EF are characterized by unity and diversity, meaning that they are both overlapping, and yet distinct (Miyake et al., 2000), children with ADHD may be characterized by somewhat differing patterns of regulation problems (Derefinko et al., 2008; Milich, 2001; Miller et al., 2010; Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005; Solanto et al. 2001; Sonuga-Barke, 2005). For example, there may be one group of children who are more primarily impulsive with problems associated with response inhibition and increased response variability, a second group of children who exhibit problems with higher-order cognition, effortful control, and multi-tasking, and a third group of children with relatively intact task performance (Castellanos et al., 2006; Fair, Bathula, Nikolas, & Nigg, 2012; Nigg et al, 2005). Specific executive function deficits have been shown to be dissociable such that subgroups of children with ADHD may be affected by problems in only one area of EF (Fair, Bathula, Nikolas, & Nigg, 2012; Miller et al., 2010; Sonuga-Barke, Bitsakou, & Thompson, 2010). Since current work suggests that various subgroups of children with ADHD may be characterized by differing patterns of EF problems, it is possible that children with ADHD may be able to be divided into two, three,

or more subgroups based on EF profiles (Fair, Bathula, Nikolas, & Nigg, 2012; Nigg, et al., 2005; Sonuga-Barke, Bitsakou, & Thompson, 2010; Willcutt et al., 2005).

In line with this idea, EF abilities in children and adults have been associated with activity in specific, and somewhat distinct, areas of the prefrontal cortex. Set-shifting appears to be localized to the left inferior prefrontal cortex (McDonald et al., 2005), whereas response inhibition taps more medial and left inferior prefrontal structures (Aron, Robbins, & Poldrack, 2004; Casey et al., 1997; Moriguchi & Hiraki, 2009; Rogers, Andrews, Grasb, Brooks & Robbins, 2000). Further, performance on set-shifting and response inhibition tasks are only moderately correlated (Lehto, Juujarvi, Kooistra & Pulkkinen, 2003; Miyake, et al., 2000). Thus, children with ADHD may fall into distinct EF subgroups based on somewhat differing neurobiological activity patterns.

Examination of EF profiles within ADHD could further theory and models of ADHD by providing information on how best to parse the behavioral heterogeneity of children with this disorder. In addition, use of EF subtypes within ADHD could facilitate a better understanding of mechanisms of ADHD and its common comorbid conditions. For example, other disruptive behavior disorders, including Oppositional Defiant Disorder (ODD) and Conduct Disorder (CD), are highly comorbid with ADHD (Angold, Costello, & Erkanli, 1999), and children with these disorders often exhibit impairment in inhibitory control, similar to children with ADHD (Oosterlaan & Sergeant, 1998; Raaijmakers et al., 2008; Schachar et al., 2000; Sergeant, Geurts, & Oosterlaan, 2002). Anxiety disorders are also highly associated with ADHD (Angold, Costello, & Erkanli, 1999), and children with anxiety disorders exhibit deficits in EF, specifically problems with episodic memory and slow processing speed (Airaksinen, Larsson, & Forsell, 2005).

Finally, ADHD is associated with learning problems and learning disorders with 20 to 30 percent of children with ADHD exhibiting a diagnosable learning disorder (Hinshaw, 1992; Mayes, Calhoun & Crowell, 2000). Some research suggests that EF impairment, particularly problems with set-shifting, may explain the association between ADHD and learning problems (Bull, Espy, & Wiebe, 2008). Furthermore, EF impairment, particularly set-shifting, is associated with academic problems (Biederman et al., 2004; Bull & Scerif, 2001; Gathercole & Pickering, 2000) and lower intelligence (Mahone et al., 2002). Therefore, EF profiles may provide important information about the mechanisms underlying common comorbid presentations and learning problems in children with ADHD.

In sum, work to date suggests a key question: Are there subtypes, or subgroups, of individuals within the ADHD diagnostic category who are characterized by impaired EF vs. intact task performance or even by specific profiles of EF impairment? The present study seeks to further evaluate whether EF subtypes are identifiable within ADHD using an abbreviated battery of EF measures that might be easily utilized in clinical practice. Although the study was exploratory in nature, hypotheses were that there would be at least two EF subtypes. Specifically, the predicted two-cluster solution was 1) children with EF deficits, and 2) children without EF deficits (Biederman et al., 2004). It was also hypothesized, however, that more than two clusters may exist based on specific EF abilities. Based on the measures available and prior research, a predicted three-cluster solution was

(1) children with inhibitory control problems, (2) children with set-shifting/speed problems, and (3) children without EF deficits, based on current multiple pathway model of ADHD (Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005; Sonuga-Barke, 2005; Sonuga-Barke et al., 2010). It was hypothesized that these groups would be able to be externally validated via differential associations with comorbid symptomatology and intelligence and academic achievement.

METHOD

Participants

Participants were 357 children, between the ages of 6 and 13, recruited through the community who completed an extensive, multi-stage, diagnostic screening procedure. All children included in the current study met DSM-IV criteria for ADHD as outlined below with 191 children meeting criteria for the DSM-IV combined type [ADHD-C], 105 children for the DSM-IV predominantly inattentive type [ADHD-PI], and 6 for the predominantly hyperactive-impulsive type [ADHD-PHI]. Fifty-five children exhibited subthreshold ADHD symptoms (i.e., exhibited five symptoms of ADHD or exhibited cross-situational manifestation of symptoms) and were retained in analyses in order to better capture the continuum of ADHD symptom severity (Haslam et al., 2006; Levy, et al., 1997). 332 families participated in the study, and 25 of these families had two siblings participate. 111 children met criteria for ODD, 20 met criteria for CD, 54 met criteria for Generalized Anxiety Disorder (GAD) and 18 met criteria for Major Depressive Disorder (MDD). Mean symptom counts and other demographic information can be found in Table 1.

Procedure

Families were recruited using a broad community based strategy that employed mass mailings to parents in local school districts, flyers posted in clinics, and public advertisements seeking children for a study of attention, attention problems, and ADHD. Families who volunteered to participate were then screened using a multi-stage screening process. At Stage 1, all families were screened by telephone to determine whether they were eligible for the study. Youth who were prescribed long acting psychotropic (e.g., antidepressants) or who presented with major medical conditions, head injury, history of seizures or loss of consciousness, neurological impairments, or a previous diagnosis of mental retardation or autism, were excluded from the study in order to facilitate study of ADHD-specific EF impairment and associated problems. Parents of children taking psychostimulant medication were asked to consult with a physician about discontinuing medication for 24 to 48 hours prior to the laboratory visit to ensure a more accurate measure of cognitive performance. Families were screened out here only if they failed to attend the laboratory visit or if parent and teacher ratings could not be obtained.

Subsequent to the telephone screen, families came to campus to participate in up to two laboratory visits. At Stage 2, the first laboratory visit, parents of the participants completed the Child Behavior Checklist/Teacher Report Form (CBCL/TRF; Achenbach, 1991), the Conners Rating Scales-Revised (Conners, 1997), and the ADHD Rating Scale (ADHD-RS, DuPaul, Power, Anastopolous, and Reid, 1998). These forms were also sent to the child's

teacher for completion. Further, parents completed a structured clinical interview to ascertain symptom presence, duration, and impairment. At this point, children also completed IQ and achievement testing. At Stage 3, families were invited back for a second laboratory visit. At this visit, children completed EF testing.

Measures

Symptoms: ADHD, ODD, CD, MDD, GAD—Symptoms of ADHD, ODD, CD, GAD, and MDD were obtained via parent report on a well-established diagnostic interview. For participants who participated between 1997 and 2001, the Diagnostic Interview Schedule for Children (DISC-IV; Schaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000) was completed with the parent by telephone or during on-campus visits. A trained graduate student or advanced undergraduate with at least ten hours of training administered the DISC-IV. For ADHD, if children met criteria as listed in the DSM-IV-TR regarding age of onset, duration, impairment, and cross-situational manifestation, an “or” algorithm was used where up to three teacher-rated symptoms on the ADHD-RS could be added to the parent’s endorsed total to get the total number of symptoms for the child (Lahey et al., 1994).

For participants who participated from 2002 to 2008, youth and their primary caregiver completed the Kiddie Schedule for Affective Disorders and Schizophrenia (KSADS-E; Puig-Antich & Ryan, 1986). Training requirements were equivalent to or more stringent than that of the DISC-IV. Fidelity to interview procedure was checked by having the interview recorded with 5 % reviewed by a certified trainer. The data from interview and parent and teacher rating scales were then presented to a clinical diagnostic team consisting of a board certified child psychiatrist and licensed clinical child psychologist. They were allowed to use the same “or” algorithm described above in regard to ADHD diagnosis and symptoms.

Pooling the data across families that received the KSADS-E and DISC-IV was justified based on the analysis of agreement between the two methods in 430 youth for whom parent completed both a KSADS-E and a DISC-IV. The two interviews had adequate agreement for total number of symptoms (inattention, ICC=.88, hyperactivity, ICC=.86), presence of six or more symptoms of ADHD (kappa=.79), and presence of ADHD (defined as six or more symptoms + cross situational impairment in each interview for purposes of computing agreement; kappa=.79).

Intelligence and Achievement—Children were administered a reliable three-subtest short form of the Wechsler Intelligence Scale for Children-Third Edition (WISC-III, prior to 2003) or Fourth Edition (WISC-IV) comprised of the Block Design, Information, and Vocabulary subtests of the WISC-IV (Sattler, 2008; Wechsler, 1991; 2003). The short form was administered by a trained undergraduate student to provide a measure of estimated Full Scale Intelligence Quotient (IQ). The Full Scale IQ was computed as a standardized score based on age-based norms. Children also completed selected subtests from the Wechsler Individual Achievement Test-Second Edition (WIAT-II; Wechsler, 2001) to assess reading, mathematics, and spelling academic skills. Academic achievement scores for spelling, reading and math skills from the WIAT-2 were also computed as standardized scores, based on age-based norms.

Executive Function—Children completed laboratory tasks to measure EF, including response inhibition, response variability, speed, and set-shifting. To measure response inhibition and response variability, children completed the tracking version of the Stop Task (Logan, Schacher, & Tannock, 1997), which requires the child to respond rapidly to the stimulus of an X or an O on a computer screen with one of two keys. On a quarter of the trials, a tone follows the presentation of the X or O, indicating that the child should withhold their response. The STOP task has been well-validated, has an alpha reliability greater than .80, and is used to measure the ability to suppress a motor response on cue (Band, van der Molen, & Logan, 2003; Logan, 1994). Stop Signal Reaction Time (i.e., SSRT) was computed by subtracting mean stop signal latency from mean go response time and served as a measure of response inhibition (Logan, Schacher & Tannock, 1997). Within child variability of reaction time on “go” trials served as a measure of response variability (Russell et al. 2006).

The Trail Making Task, Parts A and B, a subtest of the Halstead-Reitan Neuropsychological Battery (Reitan, 1986), was also administered to provide a measure of speed and set-shifting ability. This measure requires the participant to trace letters and numbers as quickly as possible without errors and is an index of frontal lobe integrity (Reitan, 1958; Spreen & Strauss, 1991) and has demonstrated high inter-rater reliability as well as alternate forms of reliability ranging from .78 to .92 (Bowie & Harvey, 2006). Time to complete Trails A served as a measure of speed, and number of errors during Trails B served as measure of set-shifting.

Data Analysis

Two-step cluster analysis was conducted in SPSS on standardized EF measures (i.e., response inhibition, response variability, speed and set-shifting). Two-step cluster analysis has been shown to lead to more objective solutions than K-means cluster analysis because the number of clusters is automatically determined using the Log-likelihood distance measure and the Bayesian Information Criterion (BIC) criterion to determine the best solution (Chiu, Fang, Chen, Wang & Jeris, 2001; Bacher, Wenzig, & Vogler, 2004). These calculations are performed in two phases. During the first phase, the best number of clusters in the data is determined based on the BIC (with smaller BIC indicating better model fit), and an estimate of the number of clusters is provided. Since its development, this technique has been successfully used in studies of the social sciences (e.g., Dumlu et al., 2011; Facca & Allen, 2011; Guidi et al., 2011; Kaye & Johnson, 2011, McCrimmon et al., 2012) and most recently used in clustering EF profiles in individuals with autism (Sadler, Meagor, & Kaye, 2012). Further validation of the cluster solution was conducted using a validation method in which 50% of the cases were randomly selected 100 times and two-step cluster analysis was performed on the subsamples.

In order to externally validate the best-fitting cluster solution, multivariate analysis of variance (MANOVA) and follow-up univariate ANOVAs were conducted to evaluate whether the clusters exhibited mean differences in intelligence, academic achievement, and ADHD, ODD, CD, GAD or MDD symptoms.

RESULTS

Cluster/Profile Solution

To determine whether children with ADHD clustered into distinct groups based on their EF performance, two-step cluster analysis was performed in SPSS. For the two-step cluster analysis in SPSS and based on the Log-likelihood distance measure, a 3-cluster provided the best fit to the data ($BIC=810.3$, $LL=1.92$). Based on the descriptive statistics shown in Table 2, Cluster 1 ($n=65$, 18% of the total sample) was characterized by relatively poor performance on the Trails A and B task, henceforth termed “poor speed/set-shifting.” Cluster 2 ($n=93$, 26% of the total sample) was characterized by relatively poor response inhibition, henceforth termed “poor response inhibition,” and Cluster 3 ($n=199$, 56% of the total sample) was characterized by children with relatively intact task performance, henceforth termed “intact.”

In order to validate the reliability of the 3-cluster solution using a validation method in which 50% of cases were randomly selected, and two-way cluster analysis was performed 100 times on the subsamples. Based on these replication analyses, a 3-cluster solution was supported 53% of the time compared to 2-cluster and 4-cluster solutions, which were supported 43% and 5% of the time respectively. It should be noted that the two-cluster solution, supported 43% of the time, was characterized by an intact task performance cluster and an EF dysfunction cluster. The EF dysfunction cluster displayed weaker performance on all executive function tasks as compared to the intact task performance group. The 3-cluster groupings were similar to those portrayed above. That is, one example of a 50% subsample 3-cluster solution produced Cluster 1 ($n=27$, 15%), characterized by poor set-shifting/speed ability; Cluster 2 ($n=39$, 22%), characterized by poor response inhibition; and Cluster 3 ($n=109$, 62%), characterized by intact task performance.

External Validation of the 3-Cluster Solution

As indicated in Table 2, approximately half of each cluster was diagnosed with the ADHD-C subtype, in line with idea that the current DSM-IV ADHD subtypes do not reliably parse EF heterogeneity within ADHD. The clusters did not differ on the variables of gender or ethnicity; however the intact task performance group was significantly older ($F[2,356]=17.75$, $p<.001$, $\eta^2=.09$) than the two EF dysfunction groups.

ADHD, ODD, CD, GAD & MDD Symptoms—The 3-cluster solution from the full sample was then externally validated with inattentive and hyperactive-impulsive ADHD, ODD, CD, GAD, and MDD symptoms. The MANOVA conducted to examine mean cluster differences in ADHD, ODD, CD, GAD and MDD symptoms was significant ($F[12,572]=4.78$, $p<.001$, $\eta^2=.09$). Follow-up ANOVAs revealed significant cluster differences in ODD symptoms ($F[2,290]=6.23$, $p=.002$, $\eta^2=.04$), CD symptoms ($F[2,290]=14.23$, $p<.001$, $\eta^2=.09$), MDD symptoms ($F[2,290]=7.30$, $p=.001$, $\eta^2=.05$), and hyperactive-impulsive ADHD symptoms ($F[2,293]=7.15$, $p=.001$, $\eta^2=.05$), but not inattentive ADHD symptoms ($F[2, 293]=.705$, $p=.495$, $\eta^2=.01$) or GAD symptoms ($F[2, 290]=.83$, $p=.439$, $\eta^2=.01$). Posthoc Tukey tests indicated that ODD symptoms and hyperactive-impulsive ADHD symptoms were significantly higher in the poor set-shifting/

speed cluster compared to the other clusters ($p < .05$, $\eta^2 = .01-.09$), suggesting that this subgroup exhibited significantly higher disruptive behavior problems, although—at a descriptive level—both executive dysfunction groups had more symptoms than the intact task performance cluster. MDD symptoms were significantly higher in the intact task performance cluster compared to the other clusters ($p < .05$, $\eta^2 = .05$).

IQ and Academic Achievement—ANOVA indicated significant cluster differences in intelligence ($F[2, 351] = 7.04$, $p = .001$, $\eta^2 = .04$) with the poor set-shifting/speed cluster exhibiting significantly lower intelligence than the other two clusters ($p < .05$). MANOVA indicated significant cluster differences in academic achievement ($F[6, 430] = 2.93$, $p = .008$, $\eta^2 = .04$), with significant follow-up ANOVAs for spelling ($F[2, 216] = 6.01$, $p = .003$, $\eta^2 = .05$) and mathematics ($F[2, 216] = 6.60$, $p = .002$, $\eta^2 = .06$), but not for reading ($F[2, 216] = 2.67$, $p = .071$, $\eta^2 = .02$). Academic achievement was significantly lower in the poor set-shifting/speed cluster compared to the intact performance cluster ($p < .01$). At a descriptive level, the response inhibition cluster exhibited slightly lower academic achievement than the intact task performance cluster, although this difference was not statistically significant.

Secondary Checks

All external validation analyses were rerun controlling for child age, gender, and ethnicity with no significant changes in findings.

DISCUSSION

Via use of an abbreviated neuropsychology battery, this study explored whether EF subtypes within ADHD might provide a better means by which to parse heterogeneity within the ADHD diagnostic category. Based on cluster analysis, there is support for the existence of EF clusters within the ADHD diagnostic category. Specifically, there appears to be three EF impairment clusters, or subtypes, within the present sample, based on the short EF battery utilized. In line with prior theory (Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005; Solanto et al., 2001; Sonuga-Barke, 2005; Sonuga-Barke, Bitsakou, & Thompson, 2010) and study hypotheses, these clusters were characterized by poor set-shifting/speed, poor inhibitory control, and relatively intact task performance. These clusters were able to be meaningfully validated via use of other disruptive behavior and anxiety/mood symptoms, as well as intelligence and academic achievement. Namely, the poor set-shifting/speed cluster was characterized by significantly greater hyperactive-impulsive ADHD and ODD symptoms as well as lower intelligence and academic achievement than the other two clusters.

The present study results suggest that the current three DSM-IV ADHD subtypes, based on behavioral symptom presentation, might—with further empirical support—be able to be replaced by subtypes based on EF profiles. In line with prior work (Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005; Willcutt, et al., 2005), there appear to be at least two EF subtypes within ADHD, and possibly more. Based on the current battery, these subtypes were poor set-shifting/speed, poor inhibitory control, and relatively intact task performance. Thus, there may be at least a subgroup of children with ADHD who have intact task performance, although it should be noted that we cannot rule out that this group had some other type of deficit. Interestingly, this group of children had higher depressive symptoms. However, they

also did not exhibit academic problems or sub-par intelligence. Thus, this group of children might be in least need of academic intervention, at least compared to other children with ADHD.

The subgroup of children with ADHD with poor set-shifting/speed appeared to be most impaired, relative to both the intact task performance and the poor response inhibition subgroups. The poor set-shifting/speed subgroup experienced lower academic achievement, lower intelligence, and increased ODD and hyperactive-impulsive ADHD symptoms compared to other children with ADHD. These findings are in line with work suggesting that EF deficits contribute to academic underachievement in children with ADHD (Biederman, et al., 2004; Bull, Espy, & Wiebe, 2008), as well as comorbid symptomatology (Coolidge, Thede, & Young, 2000; Fischer, Barkley, Smallish, & Fletcher, 2005). In fact, some recent work suggests that children with ADHD and EF impairment may be more severely impaired than those children without EF impairment in regard to school performance and academic abilities (Lambek et al., 2010). This might be particularly true for children with poor set-shifting or multi-tasking ability, skills which appear to be particularly useful in the classroom (Bull, Espy, & Wiebe, 2008; Bull & Scerif, 2001). That is, poor set-shifting ability may limit children's ability to think flexibly and multi-task, important components of their ability to flexibly adapt to their surroundings (Hill, 2004; Wechsler, 1971). Thus, set-shifting may be important to assess in order to be able to provide targeted intervention in the classroom for those children who need it most.

The poor response inhibition subgroup exhibited a behavioral and cognitive profile that was descriptively intermediate between the poor set-shifting/speed and intact task performance groups. In fact, an alternative way to conceptualize the clusters might be via gradations of EF impairments with the poor set-shifting/speed cluster being most severely impaired, the poor response inhibition cluster being moderately impaired, and the intact task performance cluster being relatively unimpaired. However, the descriptive information on EF within cluster (shown in Table 2) does not support that conceptualization.

Alternatively, it is possible that the associated neurobiological correlates of the two clusters account for the discrepancy. That is, because set-shifting taps dorsolateral prefrontal cortex function (Cabeza and Nyberg, 1997; Konishi et. al., 1998), the poor set-shifting/speed group might exhibit more generalized deficits in functional domains relying on effortful control of behavior, such as academic achievement and hyperactivity-impulsivity and ODD. In contrast, the group exhibiting poor response inhibition, which taps more medial prefrontal structures, might exhibit deficits in approach-like behaviors such as reward sensitivity that are less related to academic achievement and other DBD symptoms (Rogers, Andrews, Grasb, Brooks & Robbins, 2000). This idea cannot be directly tested in the current study, but is an important direction for future work.

The current study's results support the idea that there are EF subtypes within the ADHD diagnostic category and suggest that the EF subtypes may merit further attention in assessment and diagnosis of ADHD for DSM-V (Nigg, Rohde, & Todd, 2008; Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005). As noted, the DSM-IV-TR (APA, 1994) subtypes and DSM-5 (APA, 2013) presentations of ADHD (ADHD-PI, ADHD-PH, and ADHD-C)

have not been well validated in relation to longitudinal stable or via use of external correlates (Lahey et. al, 1994; Willcutt et al., 2005). In line with this prior work, the current study suggests that ADHD-C subtype is a heterogeneous group in relation to EF characteristics. ADHD-C subtype appears to include children with poor set-shifting/speed, poor response inhibition, and relatively intact task performance. EF profiles may have promise as an alternative subtyping approach with important implications for assessment of children with ADHD. Profiles of EF impairment may be one way to increase homogeneity within the ADHD diagnostic category. This—in turn—has implications for etiological study of ADHD such that EF impairment could be a primary deficit, or possible endophenotype, in a subgroup of children with ADHD (Doyle, et al., 2005; Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005). Further, the use of EF profiles might allow for more targeted academic accommodations and interventions tailored to specific profiles of EF deficits (Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005; Rueda et. al., 2005). As an example, training of executive functioning, such as working memory and speed, have proven promising for some children with ADHD (Klingberg, et. al, 2005; Mackey, Hill, Stone & Bunge, 2011).

However, more research on this topic is needed. One important limitation of the current study was the small battery of EF tasks used. Therefore, the present study cannot rule out the possibility that the group of children falling into the intact task performance cluster was not actually a group of children with some type of EF impairment that was not evaluated in the present study (see Fair et al., 2012). Additionally, shared method variance (in that multiple measures came from the same task) might have influenced cluster characteristics. Therefore, it will be important to replicate these findings using a larger, clinically-relevant EF battery. Further, some work has suggested that EF questionnaires may be more sensitive to EF impairments than psychological tests (Barkley & Murphy, 2010). Additionally, our use of a 3-subtest IQ test may have led to overestimates of IQ in children with ADHD. Thus, the task performance assessment of EF and abbreviated assessment of IQ in the present study may be considered a limitation.

It is important to note that children in the “intact” task performance group exhibited intact performance relative to the other clusters and may exhibit EF impairment in areas not assessed in the current study or in other domains not assessed in the present study (e.g., relationships, self esteem). It should be noted that, although significant, the symptom differences between the two impaired EF groups were relatively small, although these differences are likely to be clinically significant due to the current DSM subtyping approach that relies on small differences in symptoms to determine subtypes, or presentations (APA, 2000; 2013). Future directions for this work include exploration of the effects of age on cluster membership, replication in other samples (e.g., clinical and/or epidemiological) using larger EF batteries and EF questionnaires, and longitudinal studies to evaluate whether these subtypes are temporally stable (Lahey et al., 2005). Finally, although two-step cluster analysis revealed a three-cluster solution as the best fit for the data, alternate methods of subtyping should be explored.

Overall, the current study provides support for the concept that EF subtypes can be seen within ADHD. There may be three EF subgroups within ADHD, and they may exhibit somewhat distinct profiles of comorbid problems, including academic achievement. EF

assessment in children with ADHD may allow more tailored academic intervention approaches tailored to children's individual needs, based on their EF profile.

Biographies

Bethan Roberts, M.S. is a doctoral student in the clinical psychology program at the University of Kentucky whose research interests include the etiology and assessment of ADHD as well as biological correlates of ADHD. She earned her M.S. from the University of New Orleans.

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Table 1

Descriptive Statistics for the Sample

	ADHD n=357	
Boys <i>n</i> (%)	232	(65%)
Ethnic Minority <i>n</i> (%)	83	(23%)
Age	9.9	(1.5)
ADHD Symptoms		
Inattentive	6.8	(2.3)
Hyperactive-Impulsive	5.8	(2.7)
ODD Symptoms	2.8	(2.5)
CD Symptoms	.65	(1.3)
MDD Symptoms	1.9	(1.6)
GAD Symptoms	1.2	(2.5)
Academic Achievement		
WIAT Reading	100.0	(14.4)
WIAT Math	102.3	(15.5)
WIAT Spelling	97.2	(13.6)
Full Scale IQ	102.9	(14.9)
EFs		
Response Inhibition (ms)	304.3	(157.2)
Response Variability (ms)	201.9	(63.3)
Set-Shifting (errors)	.76	(1.2)
Speed (s)	22.8	(10.5)

Note.

ADHD=Attention-Deficit/Hyperactivity Disorder. ODD=Oppositional-Defiant Disorder. CD=Conduct Disorder. MDD=Major Depressive Disorder. GAD=Generalized Anxiety Disorder. WIAT=Wechsler Individual Achievement Test.

EF Clusters Within ADHD

Table 2

	RI	RV	Speed	SS-E	ADHD-C%	Female%	Minority%	Age
<i>Mean (standard deviation)</i>								
Cluster 1 <i>n</i> =65	297.5 ^a (145.5)	202.9 ^a (51.1)	39.7 ^a (10.4)	1.69 ^a (2.2)	55.4	31.3	31.2	9.3 (1.5)
Cluster 2 <i>n</i> =93	489.4 ^a (127.0)	246.6 ^a (67.1)	21.7 ^a (6.8)	0.69 ^b (.83)	64.5	41.9	28	9.4 (1.4)
Cluster 3 <i>n</i> =199	220.0 ^a (82.9)	180.6 ^a (53.6)	17.8 ^a (4.9)	0.49 ^{ab} (.72)	47.7	33.2	24.6	10.3 (1.5)
Full Sample <i>n</i> =357	304.3 (157.2)	201.85 (63.3)	21.86 (9.9)	.068 (1.1)	42.3	35.1	26.7	9.9 (1.5)

Note.

RI=Response Inhibition. RV=Response Variability. Speed=Trails A Time. SS-E=Set-shifting Errors. ADHD-C%= percentage of each cluster with ADHD-C subtype diagnosis. Like superscripts denote significant differences between groups, $p<.05$.

Table 3

Cluster Differences in External Validators

Cluster	η^2	Poor set-shifting/speed	Poor response inhibition	Intact executive function
<i>Mean (standard deviation)</i>				
<u>Psychopathology</u>				
Inattention SX	.01	6.82 (2.68)	6.88 (2.05)	6.69 (2.28)
Hyperactive-Impulsive SX	.05	6.69 (2.45) ^a	6.13 (2.48) ^b	5.42 (2.84) ^{ab}
Oppositional Defiant Disorder SX	.04	3.46 (2.48) ^a	3.29 (2.70) ^b	2.34 (2.36) ^{ab}
Conduct Disorder SX	.09	0.84 (1.12) ^a	1.24 (1.85) ^b	0.35 (.860) ^{ab}
Major Depressive Disorder SX	.05	1.84 (1.62) ^a	1.38 (2.13) ^{ab}	2.08 (1.28) ^b
Generalized Anxiety Disorder SX	.01	1.01 (2.31)	1.12 (2.20)	1.37 (2.76)
<u>Academic Achievement</u>				
WIAT Reading	.04	96.31 (14.80)	99.64 (14.35)	101.61 (14.17)
WIAT Math	.06	94.95 (13.92) ^a	100.42 (17.87)	104.53 (14.91) ^a
WIAT Spelling	.05	92.06 (13.03) ^a	93.67 (13.81)	99.49 (13.25) ^a
Full Scale IQ	.04	96.89 (13.49) ^{ab}	103.04 (14.21) ^a	104.78 (15.19) ^b

Note.

SX=Symptoms. Like superscripts denote significant differences between groups, $p < .05$.