I, Tanya N. Antonini, hereby submit this original work as part of the requirements for the degree of Doctor of Philosophy in Psychology.

It is entitled:
Hot and Cool Executive Functions in Children with ADHD and Comorbid Disruptive Behavior Disorders

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Hot and Cool Executive Functions in Children with ADHD and Comorbid Disruptive Behavior Disorders

A Dissertation Submitted to the
Graduate School
of the University of Cincinnati
in partial fulfillment of the
requirements for the degree of

Doctor of Philosophy

In the Department of Psychology
of the College of Arts and Sciences

By

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August 2014
M.A. University of Cincinnati
May 2011

Committee Chair: Jeff Epstein, Ph.D.
Abstract

Attention-Deficit/Hyperactivity Disorder (ADHD) is one of the most commonly diagnosed disorders in childhood. Although research suggests strong associations between the disorder and deficits in hot and cool executive functions (EFs) at a group level, deficits among individual children with ADHD are not universal. One potential moderator of executive dysfunction may be the presence of a comorbid disruptive behavior disorder (DBD; oppositional defiant disorder, conduct disorder). This study examined the association between EFs and comorbid DBDs in children with ADHD. It was hypothesized that all participants with ADHD would perform more poorly on cool EF tasks than controls, but that only those with a comorbid DBD would perform more poorly on hot EF tasks. One-hundred, thirty-one children (7-12 years old) participated in the study: 67 with ADHD - DBD, 34 with ADHD+DBD, and 30 controls. Cool EF scores included correct trials on a spatial span task and correct responses and perseverative errors on a card sorting test. Hot EF scores included discounting gradients from a delay discounting task and net scores on a gambling task. Primary analyses examined group differences in these variables. Several secondary analyses were also conducted. First, the effects of intellectual functioning and academic achievement scores on group differences were examined. In addition, ADHD subtype was examined as a moderator of group differences in cool and hot EF performance. Lastly, the continuous relationship between oppositional defiant symptoms, ADHD symptoms, and executive performance was explored. Results indicated that the ADHD - DBD and ADHD+DBD groups performed more poorly on cool EF tasks than controls, but did not differ from each other. There was no significant Group effect for either hot EF score. Secondary analyses indicated that many differences in cool EFs were not significant after controlling for intellectual functioning or academic achievement. In addition, ADHD subtype did not moderate the
relationship between EF performance and the presence of a comorbid DBD. Finally, analyses examining the relationship between symptoms and EF scores indicated that cool EF scores were significantly associated with the number of ADHD symptoms, but not oppositional defiant disorder symptoms. Hot EF scores, however, were not significantly associated with either ADHD or oppositional defiant disorder symptoms. In conclusion, consistent with prior research, ADHD was associated with cool EF deficits. In contrast with other studies, however, comorbid DBDs were not associated with decrements in hot EFs. Given the non-significant group differences in hot EF performance between the ADHD+DBD and ADHD - DBD groups, results do not support the notion that comorbid DBDs account for heterogeneity in EFs across children with ADHD. Factors related to the design of this study may have contributed to the lack of group differences in hot EFs. Perhaps the sample was too young to understand the hot EF tasks. Alternatively, task stimuli may not have had the motivational salience needed to capture deficits in hot EFs. Future research should include additional EF tasks, as well as imaging, to better understand differences in brain structures/function that may contribute to EF deficits in children with ADHD, with and without comorbid conditions.
Acknowledgements

The work presented in this dissertation document would not have been possible without the help of multiple individuals at the Cincinnati Children’s Hospital Center for ADHD. First and foremost, thank you to my graduate school advisor, Jeff Epstein, for all of his assistance during this project, as well as his never ending patience and editorial skills throughout my graduate school career. Thank you also to my fellow graduate students at the Center for ADHD, Megan Narad and Kate Kingery, for their extensive support throughout these past six years. In addition, I would like to acknowledge all of the other researchers and clinicians at the Center for ADHD for their assistance with this study’s design and recruitment. Furthermore, I must thank all of the research coordinators for their help with this project, as well as the other studies from which I have published data. Lastly, thank you to all of the families who agreed to participate in this study.
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Hot and Cool Executive Functions in Children with ADHD and Comorbid Disruptive Behavior Disorders

Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder characterized by atypical levels of attention, hyperactivity, and/or impulsivity. An estimated 8.7% of children between the ages of 8 and 15 in the United States meet diagnostic criteria for ADHD, making it one of the most common disorders in childhood (Froehlich et al., 2007). Numerous studies have investigated the neurocognitive processes associated with ADHD, with the goal of increasing our understanding of the disorder and its etiology. Much of the neuropsychological research within the ADHD literature has been focused on executive functions (EFs), which are commonly understood to encompass the cognitive abilities responsible for maintaining internal goals to perform task-relevant behaviors. They include, among others, working memory, inhibitory control, problem-solving, reasoning, and decision making (Miller & Cohen, 2001; Miyake et al., 2000).

The majority of ADHD EF research has focused on “cool” non-emotionally-laden EFs (e.g., inhibitory control, working memory) that are typically subserved by the dorsolateral prefrontal cortex (DLPFC), which has strong connections to the thalamus, basal ganglia, hippocampus, and association areas of the neocortex (Zelazo & Mueller, 2002). In comparison with typically-developing children, studies suggest that children with ADHD have impairments in several cool EFs, including working memory (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005), motor inhibition (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005), planning, and problem solving (Kopecky, Chang, Klorman, Thatcher, & Borgstedt, 2005; Romine et al., 2004; Weyandt & Willis, 1994).

In addition, there is some research suggesting that children with ADHD show poorer
performance than typically-developing children on hot EF tasks (e.g., Garon, Moore, & Waschbush, 2006; Toplak, Jain, & Tannock, 2005; Shiels et al., 2009; Solanto et al., 2001; Wilson, Mitchell, Musser Schmitt, & Nigg, 2011). Hot EFs, in contrast with cool EFs, refer to the cognitive abilities needed for motivationally or emotionally salient decision making and goal setting (Zelazo & Mueller, 2002). These abilities are subserved by the orbitofrontal and ventromedial regions of the prefrontal cortex (OF/VMPFC), which have connections to the amygdala and limbic system that are important for emotional processing (e.g., LeDoux, & Phelps, 2000; Phan, Wager, Taylor, & Liberzon, 2004). Studies examining hot EFs typically use gambling (e.g., Iowa Gambling Task), choice delay, delay discounting, or risky choice tasks to obtain measures of decision making within a motivational context. Results supporting hot EF deficits in individuals with ADHD lend support to the inclusion of emotionally-related cognition in theories of the mechanisms that underlie ADHD. Indeed, updated theories take into account multiple cognitive deficits and suggest several possible pathways to the disorder. For example, Sonuga-Barke’s (2002, 2003) dual-pathway model includes both “executive dysfunction” and “delay aversion,” thus accounting for both types of neuropsychological deficits in children with ADHD. Furthermore, using “hot” and “cool” terminology, Castellanos, Milham, Sonuga-Barke, and Tannock (2006) have proposed an integrative model to explain EF impairments seen in individuals with ADHD based on dysfunction within the cortico-striato-thalamo-cortical circuitry, which includes regions tied to both hot and cool EFs (e.g. Zelazo & Mueller, 2002).

Despite the prominence of ADHD models focused on EF, these impairments are not universal across all patients with ADHD and, in fact, appear to be quite heterogeneous (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Investigators have explored a variety of moderating variables (e.g., gender, ADHD subtype) in an attempt to predict patterns of neurocognitive
deficits in children with ADHD, but have yet to find one that reliably predicts which deficits will be present in which individuals (e.g., Nigg, Blaskey, Huang-Pollock, & Rappley, 2002; Seidman, Biederman, Monuteaux, Valera, Doyle, & Faraone, 2005; Geurts et al. 2005; Faraone et al. 1998).

One understudied variable that could potentially moderate the pattern of executive impairments in children with ADHD is comorbid diagnostic status. Indeed, a substantial subset of children with ADHD meets criteria for at least one other comorbid psychological diagnosis. Disruptive behavior disorders (DBDs), which include Oppositional Defiant Disorder (ODD) and Conduct Disorder (CD), have the highest comorbidity rates with ADHD, with 45 to 84 percent of children with ADHD also meeting criteria for a DBD (Barkley, 2006). Comorbid DBDs in children with ADHD are associated with greater social problems (Booster, Dupaul, Eiraldi, & Power, 2012; Kuhne, Schachar, & Tannock, 1997; Ostrander, Crystal, & August, 2006), as well as higher rates of suspension, expulsion and school drop-out (Barkley, 1990), greater negativity in parent-child interactions (Barkley et al., 1991), and lower reading achievement (Moffitt, 1990).

In addition to psychosocial and academic difficulties, a comorbid DBD diagnosis may also be associated with specific cognitive deficits in children with ADHD. More specifically, DBDs may be associated with deficits in hot EFs. Research suggests that children with ODD perform more poorly on computerized gambling tasks than controls (Luman, Sergeant, & Oosterlaan, 2010; Matthys, van Goozen, Snoek, Van Engeland, 2004). Children and adolescents with conduct disorder also perform more poorly than controls on decision making and risky choice tasks (e.g., Daugherty & Quay, 1991; Fairfield et al, 2009). Given findings supporting the presence of these hot EF deficits in children and adolescents with DBDs, children with ADHD
and a comorbid DBD would be expected to demonstrate larger deficits in hot EFs than children with only ADHD. Indeed, using the computerized Balloon Analog Risk Task (BART), Humphreys and Lee (2011) found that children with ADHD+ODD pumped up their balloons more than children with ADHD alone, despite the risk of the balloons popping and resulting in a loss of points. In addition, Fischer, Barkley, Smallish, and Fletcher (2005) found that young adults with ADHD and comorbid CD chose to play more cards on a computerized gambling task than young adults with ADHD and no CD. Furthermore, Hobson, Scott, and Rubia (2011) found that ODD/CD symptoms, but not ADHD symptoms, were related to poor performance on the Iowa Gambling Task in adolescents with ODD/CD, ADHD ± ODD/CD, and typically-developing controls.

In contrast with hot EFs, however, most studies do not support a relationship between DBDs and cool EF deficits. For example, when comparing children with ODD to controls, studies have failed to find significant associations between ODD and performance decrements on the Tower of London, Wisconsin Card Sorting Test, the Stroop Task, Trail Making Test, and the Self Ordered Pointing Test (Klorman et al., 1999; Oosterlaan, Scheres, & Sergeant, 2005; Qian, Shuai, Cao, Chan, & Wang, 2010; Sarkis, Sarkis, Marshall, & Archer, 2005). Additionally, Thorell and Wahlstedt (2006) did not find significant relationships between the number of ODD symptoms in a population-based sample of young children and measures of inhibition, working memory or verbal fluency, after controlling for ADHD symptoms. Furthermore, Fairchild et al. (2009) did not find performance deficits on the Wisconsin Card Sorting Test in adolescents with CD, when compared with typically-developing adolescents. Studies also suggest that the presence of a comorbid DBD is not associated with any additional decrements in cool EF performance in children with ADHD. For example, when comparing children with ADHD to
those with ADHD and ODD, Klorman et al. (1999) did not find any significant differences in performance on the Tower of London or Wisconsin Card Sorting Test. However, both groups with ADHD performed more poorly on these tasks than controls. Furthermore, Dolan and Lennox (2013) found that adolescents with ADHD and CD had lower planning abilities than adolescents with only CD and typically-developing controls, suggesting that cool EF deficits are more strongly associated with comorbid ADHD status rather than CD.

Although the results of these few studies suggest that comorbid DBDs may moderate hot, but not cool, EF deficits in children with ADHD, other research reveals conflicting findings with regard to the relationship between EFs and comorbid DBDs in children with ADHD. For example, Yang et al. (2011) found both hot and cool EF deficits in children with ADHD compared with typically-developing children, after controlling for comorbid diagnoses (including ODD). In addition, Matthys and colleagues (1998) found that boys with comorbid CD and ADHD performed significantly worse than boys with CD alone on a reward/punishment task, suggesting that ADHD may contribute to hot EF impairments.

Furthermore, the differential effects of comorbid DBDs on EFs across ADHD subtypes are unknown. A variety of studies have found no support for subtype as a significant moderator for cool EFs in children with ADHD (see Willcutt, Doyle, Nigg, Farone, and Pennington, 2005 for a review). Results from a recent study comparing hot EFs across children and adolescents with combined (ADHD-C) and predominantly inattentive (ADHD-I) subtypes found no significant differences in performance on a hot laboratory task (i.e., Hungry Donkey Task; Skogli et al., in press). In addition, Toplak et al. (2005) did not find net score differences on the Iowa Gambling Test between adolescents with ADHD-C and ADHD-I, although the ADHD-C group chose the infrequent penalty decks more often and the frequent penalty decks less often
compared with the ADHD-I group. Little research, however, has been conducted to examine the association between comorbid ODD or CD and EF performance across ADHD subtypes.

In summary, children with ADHD show deficits in hot and cool EFs when compared with controls. However, patterns of executive deficits in children with ADHD are quite heterogeneous, and demographic and clinical predictors of neuropsychological deficit patterns have not been identified. Comorbid DBDs are highly prevalent in children with ADHD and may be associated with hot EF impairments. Studies examining hot and cool EFs in children with ADHD often include participants who have a variety of comorbidities, which may confound results; however, few studies have been conducted to parse EF differences between children with ADHD and children with ADHD and other comorbid disorders. Given the particularly high prevalence rates of DBDs in children with ADHD, understanding how these comorbidities are related to EFs in children with ADHD is critical for understanding the neurocognitive impairments associated with ADHD.

This study sought to 1) examine the association between comorbid DBDs and hot and cool EF deficits in children with ADHD and 2) determine whether the association between DBDs and EFs is specific to hot EFs. Hot and cool EF performance indicators were examined in children with ADHD and no comorbid DBD (ADHD - DBD), children with ADHD and a comorbid DBD (ADHD + DBD), and controls. It was hypothesized that 1) both ADHD groups would have lower cool EF scores than the control group, but would not differ from each other and that 2) the ADHD + DBD group would perform worse on hot EF tasks than the ADHD - DBD and control groups who would not differ from each other. As additional exploratory investigations, the effects of intellectual functioning and academic achievement on group differences in EF were examined. Furthermore, to examine whether dimensional indicators of
ADHD and DBD are sensitive to detect EF effects, analyses examining the relationships between EF performance and symptoms, rather than diagnostic categories, were conducted. Lastly, ADHD subtype was examined as a moderator of the association between comorbid DBDs and EF scores. To the author's knowledge, this is the first study to examine both hot and cool EFs across separate ADHD - DBD, ADHD+DBD, and control groups.

Method

Participants and Recruitment

Participants in the ADHD - DBD and the ADHD + comorbid DBD groups represent a subsample of participants recruited through the Cincinnati Children’s Hospital’s (CCHMC) Center for ADHD outpatient clinic for a larger study. Two-hundred, forty-nine parents seeking ADHD evaluations for their children were invited to allow their children to participate. Of the 163 families who consented and completed the study, 101 children met the study eligibility criteria outlined below. This sample included 67 children with ADHD - DBD and 34 children with ADHD + DBD (ODD or CD). An additional 30 typically-developing control participants were recruited through advertisements within CCHMC and from a list of families who expressed interest in research participation.

Diagnostic Classification, Inclusion Criteria, and Demographics

Confirmation of the presence or absence of a current ADHD diagnosis and assessment of other current comorbidities was accomplished with the Kiddie Schedule for Affective Disorders and Schizophrenia for School-Age Children-Present and Lifetime Version (K-SADS-PL; Kaufman, Birmaher, Brent, Rao, & Ryan, 1996), performed by trained examiners with excellent reliability. Children in both ADHD groups met full DSM-IV criteria for ADHD-Predominantly Inattention Type or ADHD-Combined Type. Those in the ADHD - DBD group had two or fewer symptoms of ODD. Those in the ADHD+DBD group met full diagnostic
criteria for either ODD (n = 33) or CD (n = 1), in addition to ADHD. Given research
documenting its low prevalence (Froehlich, et al., 2007) and diagnostic instability (Lahey,
Pelham, Loney, Lee, & Willcutt, 2005), participants with ADHD-Hyperactive/Impulsive Type
were excluded from both ADHD samples (ADHD - DBD and ADHD+DBD). Control
participants did not meet diagnostic criteria for ADHD or any other Axis I diagnosis (with the
exception of specific phobias and separation anxiety). Children in all three groups were excluded
if they met diagnostic criteria for a current mood, anxiety (with the exception of specific phobias
and separation anxiety) or psychotic disorder. In addition, children with a diagnosed or suspected
Autism Spectrum Disorder (Autism, Asperger syndrome, or Pervasive Development Disorder –
Not Otherwise Specified) were excluded, as well as children with medical illnesses or injuries
that could affect cognition (e.g., prenatal stroke). To rule out possible intellectual disabilities,
children who had estimated full scale IQ scores below 80 on the Kaufman Brief Intelligence
Tests-2 (Kaufman & Kaufman, 2004) or carried a mental retardation or intellectual disability
diagnosis were excluded from participation. Lastly, children currently prescribed stimulant or
other psychiatric medications were excluded from participation.

All participants were between the ages of 7 and 12 years old (inclusive). This age range
was chosen in order to decrease heterogeneity due to neuronal and pubertal maturational effects.
Further, this targeted age range corresponds to the time period when children are most often
diagnosed with ADHD (CDC, 2005).

Participant demographics are summarized below in Table 1. The three groups did not
significantly differ in age, gender, or race (proportion of non-White/Caucasian participants). The
groups, however, did significantly differ in ADHD subtype, $\chi^2 (1) = 7.97, p = .005$, K-BIT Full
Scale IQ scores, $F(2, 127) = 14.94, p < .0001$, WIAT-III Word Reading scores $F(2, 127) =$
14.17, \( p < .0001 \), and WIAT-III Numerical Operations scores \( F(2, 127) = 12.21, \ p < .0001 \).

There was a lower proportion of children with ADHD-Predominantly Inattentive subtype in the ADHD+DBD group than in the ADHD-DBD group (\( p = .005 \)). Compared with the control group, children in both ADHD groups had lower K-BIT Full Scale IQ (ADHD - DBD: \( p < .0001 \); ADHD + DBD: \( p < .0001 \)), WIAT-III Word Reading (ADHD - DBD: \( p = .0002 \); ADHD + DBD: \( p < .0001 \)), and WIAT-III Numerical Operations (ADHD - DBD: \( p < .0001 \); ADHD + DBD: \( p < .0001 \)) scores. The ADHD - DBD and ADHD + DBD groups did not differ significantly from each other in Full Scale IQ (\( p = .43 \)), Word Reading (\( p = .18 \)), or Numerical Operations (\( p = .77 \)) scores.
Table 1

Participant Demographics by Group

<table>
<thead>
<tr>
<th></th>
<th>ADHD - DBD (n = 67)</th>
<th>ADHD + DBD (n = 34)</th>
<th>Control (n = 30)</th>
<th>Comparisons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age: mean (SD)</td>
<td>8.88 (1.48)</td>
<td>9.56 (1.85)</td>
<td>9.00 (1.80)</td>
<td>ns</td>
</tr>
<tr>
<td>Gender: male n (%)</td>
<td>50 (75.76)</td>
<td>24 (70.59)</td>
<td>20 (66.67)</td>
<td>ns</td>
</tr>
<tr>
<td>Race/Ethnicity: n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White/Caucasian</td>
<td>50 (74.63)</td>
<td>24 (70.59)</td>
<td>26 (86.67)</td>
<td>ns (proportion of White/Caucasians vs. non-White/Caucasians)</td>
</tr>
<tr>
<td>Black/African American</td>
<td>13 (19.40)</td>
<td>8 (23.53)</td>
<td>2 (6.67)</td>
<td></td>
</tr>
<tr>
<td>Hispanic/Latino</td>
<td>3 (4.47)</td>
<td>1 (2.94)</td>
<td>1 (3.33)</td>
<td></td>
</tr>
<tr>
<td>Asian</td>
<td>1 (1.49)</td>
<td>1 (2.94)</td>
<td>1 (3.33)</td>
<td></td>
</tr>
<tr>
<td>Subtype Classification: n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADHD-C</td>
<td>32 (47.76)</td>
<td>26 (76.47)</td>
<td>n/a</td>
<td>ADHD-PI in ADHD + DBD group &lt; ADHD - DBD group</td>
</tr>
<tr>
<td>ADHD-PI</td>
<td>35 (52.24)</td>
<td>8 (23.53)</td>
<td>n/a</td>
<td>ADHD + DBD = ADHD - DBD &lt; Controls</td>
</tr>
<tr>
<td>K-BIT 2 Full Scale IQ: mean (SD)</td>
<td>104.51 (12.03)</td>
<td>101.59 (12.59)</td>
<td>116.77 (10.47)</td>
<td></td>
</tr>
<tr>
<td>WIAT-III Academic Scores</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Numerical Operations SS: mean (SD)</td>
<td>96.15 (13.66)</td>
<td>94.26 (14.89)</td>
<td>109.77 (13.16)</td>
<td>ADHD + DBD = ADHD - DBD &lt; Controls</td>
</tr>
<tr>
<td>Word Reading SS: mean (SD)</td>
<td>99.31 (14.99)</td>
<td>94.15 (16.10)</td>
<td>112.67 (9.99)</td>
<td>ADHD + DBD = ADHD - DBD &lt; Controls</td>
</tr>
</tbody>
</table>

Note. ns = not significant. ADHD-C = ADHD Combined Type; ADHD-PI = ADHD Predominantly Inattentive Type; K-BIT 2 = Kaufman Brief Intelligence Tests-2; WIAT-III = Wechsler Individual Achievement Test-III; SS = standard score. See manuscript text for group comparison statistics.
**Procedure and Measures**

This study was approved by the Cincinnati Children’s Hospital Medical Center Institutional Review Board. All parents provided their written informed consent and all children gave their assent (written if older than 10 years of age). The measures described below were completed during one study visit, within a larger battery of tasks. Participants received $50 for their study participation.

**Diagnostic and Screening Measures**

Kiddie Schedule for Affective Disorders and Schizophrenia for School-Age Children-Present and Lifetime Version (K-SADS-PL; Kaufman, Birmaher, Brent, Rao, & Ryan, 1996). The K-SADS-PL is a semi-structured interview that was developed based on the Diagnostic and Statistical Manual of Mental Disorders (American Psychiatric Association, 2000). It has good psychometric properties (Kaufman et al., 1997) and has been utilized in numerous studies to diagnose participants using DSM-IV criteria. This interview was administered to each child’s primary caregiver by an advanced graduate student to make a diagnosis of ADHD and any other possible comorbid disorders. The current study utilized the ADHD, ODD, CD, anxiety, mood, and psychosis modules.

Wechsler Individual Achievement Test-III (WIAT-III; Wechsler, 2009). The WIAT-III was administered to assess each child’s basic reading and math achievement and utilized in secondary analyses covarying for academic achievement. It is a standardized screener of achievement that provides age- and grade-based standard scores and percentiles for a variety of academic subjects. Two of the subtests within the screener were utilized: Word Reading and Numerical Operations.
Kaufman Brief Intelligence Tests-2 (K-BIT; Kaufman & Kaufman, 2004). The K-BIT was utilized in secondary analyses covarying for intellectual functioning and as an IQ estimate to ensure that participants met study inclusionary criteria. It is a standardized assessment that estimates verbal, non-verbal, and overall intelligence. This test has high reliability and validity and was administered to assess each child’s intelligence and rule out possible intellectual disability. All three subtests (Verbal Knowledge, Matrices, and Riddles) were administered to create a composite, full scale IQ score.

**Cool Executive Function Tasks**

**Computerized Spatial Span Task (SST).** To provide a measure of spatial working memory, this study utilized a computerized version of the Corsi Block Test (available at http://pebl.sourceforge.net/battery.html), which is based on the standardized task procedures developed by Kessels et al. (2000). In this task, nine squares were presented on the screen. Subgroups of the squares were lit up in a specific sequence, and the participant was instructed to click the same sequence of squares using a mouse. Two sequences of the same length were presented. If the participant clicked at least one of the two sequences correctly, the next two trials of a sequence of an increased length (one block longer) were administered. Once the participant answered two sequences of the same length incorrectly, the task was discontinued. The Total Score was used as the dependent variable, which was calculated as the raw number of correctly repeated trials.

**Computerized Berg Card Sorting Test (BCST).** The Berg Card Sorting Test (Grant & Berg, 1948) measures an individual’s ability to form, maintain, and shift cognitive set as well as to inhibit a pre-potent response. This test and its variants (e.g., Wisconsin Card Sorting Test; Nelson 1976; Heaton, 2003) have been utilized to measure cool EF in a multitude of research
studies and are strongly related to dorsolateral prefrontal integrity (e.g., Lie, Specht, Marshall, & Fink, 2006), although research suggests that card sorting performance is not mediated solely by frontal brain regions (Nyhus & Barcelo, 2009). Participants in the current study completed a brief computerized version of the Berg Card Sorting Test (BCST), which has been validated (Piper et al., 2012; available at http://pebl.sourceforge.net/battery.html). Sixty-four cards differing by shape, number, or color were presented on the screen one at a time, and the participant was asked to match each card to one of four key cards without any explanation of how to do so. The individual received “correct” or “incorrect” feedback after each match. Once the individual successfully matched a set number of cards based on the current matching rule, the rule changed without any notice, and the individual had to figure out the new sorting rule. In the current study, the computer randomly selected the order of sorting rules for each participant. Two scores from the BCST were utilized as dependent variables: raw total correct responses and total perseverative errors.

**Hot Executive Function Tasks**

**Child Version of the Iowa Gambling Task (CIGT; Garon, Moore, & Waschbush, 2006).** The Iowa Gambling Task (IGT; Bechara, Damasio, Damasio, & Anderson, 1994) is a commonly used measure of hot EF. Research indicates, however, that school-age children may not understand the IGT (Prencipe, Kesek, Cohen, Lamm, Lewis, & Zelazo, 2011). Thus, the proposed study used a simplified version of the Iowa Gambling Task modeled on the task developed by Garon, Moore and Waschbusch (2006) for use with 6-13 year old children. This computerized task used four decks of cards: two disadvantageous (decks A and B) and two advantageous (decks C and D). All cards in the disadvantageous decks had two bears on them (which indicated a gain of two points). All cards in the advantageous decks had one bear on them
(gain of one point). Two decks had frequent losses of points (one advantageous and one disadvantageous) and two had infrequent losses of points (one advantageous and one disadvantageous) denoted by tigers. Participants were told that they were going to play a card game and that bears were good but tigers were bad. They were told to try to get more bears than tigers. The task included 80 trials. The net score was calculated by subtracting the total raw number of disadvantageous cards from the total raw number of advantageous cards \[ (C + D) - (A + B) \]; positive scores reflect more draws from the advantageous decks and negative scores reflect more draws from the disadvantageous decks.

**Delay Discounting Task (DDT; Mitchell, 1999).** The DDT is a computerized task that requires individuals to decide how long they are willing to wait for a hypothetical monetary reward. During this task, participants were asked to choose between varying small immediate hypothetical rewards and a larger delayed hypothetical reward. Throughout the task, the immediate money varied from $0–$10.00 in $0.50 increments and the delayed money (always $10.00) was available after one of four hypothetical delays (7, 30, 90, or 180 days). Each possible immediate award was paired with each possible delayed reward, and these pairs were presented in a random order during the task. For example, the participant might be asked whether he/she would prefer to receive 5 dollars now or 10 dollars in 7 days. The task included 88 trials. In this study, the discounting gradient (rate at which the delayed outcome was discounted) was utilized in analyses as a dependent variable. This gradient was calculated for each participant using the hyperbolic equation: \[ V = \frac{M}{1 + kD} \], where \( V \) is the indifference point (the value at which there was no preference between the immediate item and the delayed $10.00 at each delay), \( M \) is the objective value of the delayed item ($10), and \( D \) is the delay length associated with receiving $10. \( k \) represents the gradient of the discounting, which was the unit of
measure for subsequent analyses. Larger $k$ values represent steeper discounting gradients and, thus, a greater preference for immediate rewards.

In line with criteria proposed by Johnson and Bickel (2008), the indifference points at each delay were examined for each participant. Two criteria were used to identify nonsystematic (i.e., invalid) data for deletion: 1) Any indifference point that was greater in magnitude than the preceding point by more than 20% of $10, the largest reward (i.e., > $2), was considered to be an invalid data point, and 2) If the last indifference point (180 days) was greater than the first, that data point was invalid. For children with only one invalid indifference point following these criteria, the discounting gradient ($k$) was calculated using the remaining three indifference points. However, the last indifference point within these three remaining points had to remain less than or equal to the first (criterion 2).

**Missing Data**

Outlier scores were systematically dropped from all analyses. If a participant had two or more invalid indifference points on the DDT, then all DDT data for that participant were dropped (8 ADHD - DBD, 3 ADHD + DBD, 2 controls). Additionally, all DDT data were dropped for any participant who had at least one invalid data point AND poor understanding (e.g., evident to the examiner based on test administration that the participant did not understand values of money), random responding, or variable attention, as rated by the examiner during the task (1 ADHD - DBD, 1 ADHD + DBD, 0 controls). In addition, BCST correct trials (1 ADHD - DBD, 0 ADHD + DBD, 0 controls), BCST perseverative errors (2 ADHD - DBD, 1 ADHD + DBD, 0 controls), SST total scores (2 ADHD - DBD, 2 ADHD + DBD, 0 controls), CIGT net scores (0 ADHD - DBD, 2 ADHD + DBD, 0 controls) and DDT $k$ values (6 ADHD - DBD, 1 ADHD + DBD, 1 control) that were two standard deviations or more above or below the mean were
dropped. BCST data from an additional four children (2 ADHD - DBD, 2 ADHD + DBD, 0 controls) were dropped due to poor attention/behavior and/or random responding during the task. In addition to these data that were excluded, a subset of data was also lost to technical difficulties or incomplete assessments (e.g., parent needed to leave early). Only the ADHD groups had missing data (SST: 5 ADHD - DBD, 1 ADHD + DBD; BCST: 4 ADHD - DBD, 2 ADHD + DBD, CIGT: 5 ADHD - DBD, 0 ADHD + DBD; DDT: 2 ADHD - DBD, 1 ADHD + DBD). Among the children with ADHD, those who had excluded/missing data did not significantly differ in age, IQ scores, WIAT-III scores (Word Reading, Numerical Operations), gender, ADHD subtype, or DBD status, from those with a full set of data (all ps > .05). The three control participants with excluded DDT data had higher WIAT-III Word Reading scores than the controls with DDT data, $t(28) = 2.20, p = .04$, but did not significantly differ in age, IQ scores, or WIAT-III Numerical Operations scores.

**Analyses**

**Primary Analyses**

The aim of this study was to examine the association between hot and cool EF deficits and comorbid DBDs in children with ADHD. It was hypothesized that children with ADHD-DBD and ADHD + DBD would have lower scores on cool EF tasks than controls, but would not significantly differ from each other. Additionally, it was hypothesized that children with ADHD + DBD would have lower scores on hot EF tasks than both the ADHD - DBD and control groups, but that the ADHD - DBD and control groups would not differ significantly from one another.

Across all of the analyses described below, no correction for multiple comparisons was implemented. Histograms were first generated, which showed that all variables were generally
normally distributed except DDT k values, which were corrected with a log transformation. Pearson correlations were then computed examining the relation between age and each of the hot and cool EF scores. Correlations between EF scores and full scale IQ scores and WIAT-III Wording Reading and Numerical Operations scores, which were included as covariates in secondary analyses, were also computed. In addition, correlations among the two hot EF scores and among the three cool EF scores were computed and informed how group differences in hot and cool EF scores would then be examined. Based on these correlations, group differences in hot and cool EF scores were examined with multivariate analyses of covariance (MANCOVAs) and analyses of covariance (ANCOVAs) using SAS PROC GLM. In each analysis, Group (ADHD + DBD, ADHD - DBD, control) was included as the independent variable and hot or cool EF score(s) were included as the dependent variables. Age was included as a covariate. Post-hoc Tukey comparisons were used to parse out any significant Group main effects.

**Secondary Analyses**

Several sets of secondary analyses were conducted. First, for any primary analyses that resulted in significant main effects of ADHD, follow-up regression analyses were conducted to examine the relationship between EF scores and ADHD symptom domains. Each of these models included the EF score as the dependent variable and the number of inattentive symptoms and number of hyperactive/impulsive symptoms as independent variables. Age was included as a covariate. Next, despite convincing arguments for not using IQ as a covariate in neurocognitive studies (e.g., Dennis, Francis, Cirino, Schachar, & Fletcher, 2009) ADHD studies still often control for IQ. Thus, to compare our results to others who have controlled for IQ when examining EFs in children with ADHD and examine the potential effect of IQ on any significant effects, significant statistical models (see above) were recalculated with IQ as a covariate.
Secondly, to examine the impact of academic achievement on group differences in EFs, significant analyses were also recalculated with WIAT-III Word Reading and Numerical Operations scores as covariates. In addition, to explore whether the relationship between DBD and EFs is specific to a particular ADHD subtype (i.e., Combined Type or Predominantly Inattentive Type), the control group was dropped, and cool and hot scores were included as dependent variables in multivariate and univariate models, with ADHD subtype (inattentive and combined) and comorbidity status (DBD and no DBD) as independent variables. The subtype*comorbidity status interaction was examined to determine whether ADHD subtype was a significant moderator of the relationship between the presence of a DBD and EF performance. Furthermore, separate regression models for each EF score were calculated with total ADHD symptoms and DBD symptoms (number of ODD symptoms for all participants) to investigate the continuous relationship between EF and ADHD and DBD symptoms rather than diagnostic categories. CD symptoms were not included, because the majority (82%) of participants with ADHD had no CD symptoms and only 6% had more than one CD symptom. The ADHD symptoms*ODD symptoms interaction was examined to determine whether there was an interaction effect of ADHD and ODD symptoms on EFs.

Lastly, it should be noted that all analyses were conducted a second time without the one participant who was diagnosed with conduct disorder. Results did not change and, thus, the statistics presented below include this participant.

Results

Primary Analyses

Correlations

See Tables 2-5 for bivariate correlations between age, IQ, achievement scores, cool EF
variables, and hot EF variables across all participants and within each of the three groups. Across all participants, as well as within each of the three groups, age was significantly correlated with SST total scores (all participants: \( p < .0001 \)) and BCST total correct responses (all participants: \( p = .001 \)). Similarly, across all participants, CIGT net scores (all participants \( p = .004 \)) and transformed DDT k values (all participants \( p = .01 \)) were significantly positively and negatively correlated with age, respectively. Except for the relationship between age and CIGT net scores \( (p = .87) \) within the ADHD - DBD group and the relationship between age and transformed DDT k values \( (p = .49) \) within the control group, these correlations between age and hot EFs were also significant within each group. Within the groups with significant associations between age and EF scores, younger children had lower CIGT net scores, lower SST total scores, fewer BCST correct responses, and larger transformed DDT k values. Given the presence of significant associations between age and hot and cool EF scores, all subsequent analyses examining group differences included age as a covariate.

Across all participants, IQ scores were significantly correlated with SST total scores \( (p = .01) \) and BCST total correct responses \( (p = .01) \), although these relationships, only trended towards significance within the control \( (p = .07) \) and ADHD - DBD \( (p = .06) \) groups. Across all participants, IQ was not significantly correlated with BCST perseverative errors \( (p = .56) \), or either of the hot EF scores (CIGT net scores: \( p = .30 \); transformed DDT k values: \( p = .42 \)), although there was a significant association between IQ and transformed DDT k values within the ADHD + DBD group \( (p = .04) \).

Correlations examining the relationship between the three cool EF scores indicated that across all participants, total scores on the SST were positively associated with BCST total correct responses \( (p = .0002) \) and perseverative errors \( (p = .04) \); those that had higher working memory
scores answered more trials correctly on the BCST, but unexpectedly made more perseverative errors. Further exploration within groups indicated that correlations between SST total scores and BCST total correct responses were significant for the control ($p = .04$) and ADHD + DBD ($p = .0007$) groups, but not the ADHD - DBD group ($p = .42$). The relationship between SST total scores and BCST perseverative errors was significant within the ADHD + DBD group ($p = .01$), but not within either the control ($p = .74$) or ADHD - DBD ($p = .27$) group.

With regard to the relationship between performance indicators from the hot EF tasks, CIGT net scores were not significantly correlated with transformed DDT k values ($p = .38$) across all participants. Within groups, there were non-significant but positive correlations between these two variables in the control ($p = .74$) and ADHD - DBD ($p = .13$) groups, and a non-significant but negative correlation between the variables in the ADHD + DBD group ($p = .24$). The correlations above informed which analyses were conducted to examine group differences in hot and cool EFs. Given the association between the cool EF scores, the three scores were included in a single MANCOVA. Between-groups differences in hot EF scores were examined using two separate ANCOVAs.


Table 2

*Pearson Correlation Coefficients for Age, IQ, Achievement Scores, and Executive Function Scores Across All Participants*

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>1. Age (n = 131)</td>
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<tr>
<td>2. K-BIT 2 Full Scale IQ (n = 131)</td>
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<tr>
<td>3. WIAT-III Word Reading (n = 131)</td>
<td>.07</td>
<td>.56e</td>
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<tr>
<td>4. WIAT-III Numerical Operations (n = 131)</td>
<td>.05</td>
<td>.48e</td>
<td>.54e</td>
<td></td>
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<td></td>
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<tr>
<td>5. CIGT Net Score (n = 124)</td>
<td>.26e</td>
<td>-.09</td>
<td>-.05</td>
<td>.03</td>
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<tr>
<td>6. Delay Discounting k (n = 104)</td>
<td>-.32b</td>
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<td>.01</td>
<td>-.19b</td>
<td>.09</td>
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<tr>
<td>7. SST Total Score (n = 121)</td>
<td>.46e</td>
<td>.23b</td>
<td>.25c</td>
<td>.20b</td>
<td>.01</td>
<td>-.27c</td>
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<tr>
<td>8. BCST Total Correct Responses (n = 117)</td>
<td>.29c</td>
<td>.24b</td>
<td>.48e</td>
<td>.30c</td>
<td>.12</td>
<td>-.26b</td>
<td>.35d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. BCST Perseverative Errors (n = 117)</td>
<td>.05</td>
<td>-.05</td>
<td>.04</td>
<td>-.11</td>
<td>.09</td>
<td>.04</td>
<td>.20b</td>
<td>.12</td>
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</tr>
</tbody>
</table>

*Note: K-BIT 2 = Kaufman Brief Intelligence Tests-2; WIAT-III = Wechsler Individual Achievement Test-III; CIGT = Child Version of the Iowa Gambling Task; SST = Spatial Span Task; BCST = Berg Card Sorting Task. Delay discounting k values were log transformed prior to calculation of correlations. a p < .10; b p < .05; c p < .01; d p < .001; e p < .0001.*
Table 3

*Pearson Correlation Coefficients for Age, IQ, Achievement Scores, and Executive Function Scores within the ADHD - DBD Group*

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td><strong>1. Age (n = 66)</strong></td>
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<tr>
<td><strong>2. K-BIT 2 Full Scale IQ (n = 66)</strong></td>
<td>-.01</td>
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<tr>
<td><strong>3. WIAT-III Word Reading (n = 66)</strong></td>
<td>.08</td>
<td>.56c</td>
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</tr>
<tr>
<td><strong>4. WIAT-III Numerical Operations (n = 66)</strong></td>
<td>-.08</td>
<td>.48</td>
<td>.48c</td>
<td></td>
<td></td>
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<tr>
<td><strong>5. CIGT Net Score (n = 62)</strong></td>
<td>-.02</td>
<td>-.03</td>
<td>-.06</td>
<td>-.01</td>
<td></td>
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<tr>
<td><strong>6. Delay Discounting k (n = 49)</strong></td>
<td>-.32b</td>
<td>-.05</td>
<td>.09</td>
<td>-.26a</td>
<td>.22</td>
<td></td>
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<tr>
<td><strong>7. SST Total Score (n = 60)</strong></td>
<td>.41c</td>
<td>.05</td>
<td>.00</td>
<td>-.03</td>
<td>-.09</td>
<td>-.32c</td>
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<tr>
<td><strong>8. BCST Total Correct Responses (n = 59)</strong></td>
<td>.34c</td>
<td>.24a</td>
<td>.34c</td>
<td>.16</td>
<td>.18</td>
<td>-.19</td>
<td>.11</td>
<td></td>
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<tr>
<td><strong>9. BCST Perseverative Errors (n = 59)</strong></td>
<td>.13</td>
<td>-.10</td>
<td>-.14</td>
<td>-.14</td>
<td>.10</td>
<td>.12</td>
<td>.15</td>
<td>-.04</td>
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</tbody>
</table>

*Note.* K-BIT 2 = Kaufman Brief Intelligence Tests-2; WIAT-III = Wechsler Individual Achievement Test-III; CIGT = Child Version of the Iowa Gambling Task; SST = Spatial Span Task; BCST = Berg Card Sorting Task. Delay discounting k values were log transformed prior to calculation of correlations. *p < .10; **p < .05; ***p < .01; ****p < .001; *****p < .0001.
Table 4

*Pearson Correlation Coefficients for Age, IQ, Achievement Scores, and Executive Function Scores within the ADHD+DBD Group*

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>1. Age (n = 34)</td>
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<tr>
<td>2. K-BIT 2 Full Scale IQ (n = 34)</td>
<td>-.01</td>
<td></td>
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<tr>
<td>3. WIAT-III Word Reading (n = 34)</td>
<td>.18</td>
<td>.35</td>
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</tr>
<tr>
<td>4. WIAT-III Numerical Operations (n = 34)</td>
<td>.03</td>
<td>.33&lt;sup&gt;a&lt;/sup&gt;</td>
<td>.46&lt;sup&gt;c&lt;/sup&gt;</td>
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</tr>
<tr>
<td>5. CIGT Net Score (n = 32)</td>
<td></td>
<td>.59&lt;sup&gt;d&lt;/sup&gt;</td>
<td>-01</td>
<td>.08</td>
<td>.06</td>
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<tr>
<td>6. Delay Discounting k (n = 28)</td>
<td></td>
<td>-.46&lt;sup&gt;b&lt;/sup&gt;</td>
<td>.23</td>
<td>.11</td>
<td>-.14</td>
<td>-.24</td>
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<td></td>
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<tr>
<td>7. SST Total Score (n = 31)</td>
<td></td>
<td></td>
<td>.61&lt;sup&gt;d&lt;/sup&gt;</td>
<td>.16</td>
<td>.32&lt;sup&gt;a&lt;/sup&gt;</td>
<td>.21</td>
<td>.24</td>
<td>-.22</td>
<td></td>
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<tr>
<td>8. BCST Total Correct Responses (n = 28)</td>
<td>.36&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-.05</td>
<td>.51&lt;sup&gt;c&lt;/sup&gt;</td>
<td>.17</td>
<td>.27</td>
<td>-.24</td>
<td>.53&lt;sup&gt;c&lt;/sup&gt;</td>
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<tr>
<td>9. BCST Perseverative Errors (n = 28)</td>
<td>.22</td>
<td>.00</td>
<td>.45&lt;sup&gt;b&lt;/sup&gt;</td>
<td>.02</td>
<td>.13</td>
<td>.01</td>
<td>.45&lt;sup&gt;b&lt;/sup&gt;</td>
<td>.60&lt;sup&gt;c&lt;/sup&gt;</td>
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*Note.* K-BIT 2 = Kaufman Brief Intelligence Tests-2; WIAT-III = Wechsler Individual Achievement Test-III; CIGT = Child Version of the Iowa Gambling Task; SST = Spatial Span Task; BCST = Berg Card Sorting Task. Delay discounting k values were log transformed prior to calculation of correlations.  
<sup>a</sup><i>p</i> < .10;  
<sup>b</sup><i>p</i> < .05;  
<sup>c</sup><i>p</i> < .01;  
<sup>d</sup><i>p</i> < .001;  
<sup>e</sup><i>p</i> < .0001.
Table 5

Pearson Correlation Coefficients for Age, IQ, Achievement Scores, and Executive Function Scores within the Control Group

<table>
<thead>
<tr>
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<th>1</th>
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<tbody>
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<td>1. Age (n = 30)</td>
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<tr>
<td>2. K-BIT 2 Full Scale IQ (n = 30)</td>
<td>.16</td>
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<tr>
<td>3. WIAT-III Word Reading (n = 30)</td>
<td>.13</td>
<td>.31</td>
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<tr>
<td>4. WIAT-III Numerical Operations (n = 30)</td>
<td>.45&lt;sup&gt;b&lt;/sup&gt;</td>
<td>.12</td>
<td>.32&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>5. CIGT Net Score (n = 30)</td>
<td>.37&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-.12</td>
<td>.05</td>
<td>.46&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>6. Delay Discounting k (n = 27)</td>
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<td>-.27</td>
<td>-.05</td>
<td>-.04</td>
<td>.07</td>
<td></td>
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</tr>
<tr>
<td>7. SST Total Score (n = 30)</td>
<td>.52&lt;sup&gt;c&lt;/sup&gt;</td>
<td>.33&lt;sup&gt;a&lt;/sup&gt;</td>
<td>.36&lt;sup&gt;a&lt;/sup&gt;</td>
<td>.25</td>
<td>.06</td>
<td>-.13</td>
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<td></td>
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<tr>
<td>8. BCST Total Correct Responses (n = 30)</td>
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<td>.01</td>
<td>.42&lt;sup&gt;b&lt;/sup&gt;</td>
<td>.29</td>
<td>.00</td>
<td>-.36&lt;sup&gt;a&lt;/sup&gt;</td>
<td>.38&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>9. BCST Perseverative Errors (n = 30)</td>
<td>-.21</td>
<td>-.08</td>
<td>-.12</td>
<td>-.26</td>
<td>-.08</td>
<td>-.23</td>
<td>.06</td>
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</tbody>
</table>

Note: K-BIT 2 = Kaufman Brief Intelligence Tests-2; WIAT-III = Wechsler Individual Achievement Test-III; CIGT = Child Version of the Iowa Gambling Task; SST = Spatial Span Task; BCST = Berg Card Sorting Task. Delay discounting k values were log transformed prior to calculation of correlations. <sup>a</sup>p < .10; <sup>b</sup>p < .05; <sup>c</sup>p < .01; <sup>d</sup>p < .001; <sup>e</sup>p < .0001.
Group Differences

Two ANCOVAs were utilized to examine group differences in the two measures of hot EF (transformed DDT k values, CIGT net scores), while controlling for age. The effect of Group (ADHD + DBD, ADHD - DBD, control) was not significant for transformed DDT k values, \( F(2,100) = 1.39, p = .25 \), or CIGT net scores, \( F(2, 120) = 2.14, p = .12 \), indicating that neither of the hot EF scores differed significantly across groups. Due to studies speculating that younger children may not understand gambling tasks (e.g., Prencipe, Kesek, Cohen, Lamm, Lewis, & Zelazo, 2011), data from the 7-9-year-old participants were dropped, and analyses were conducted once more to examine group differences in CIGT net scores across the 10-12-year-old participants. Results indicated that the three groups did not significantly differ, \( F(2, 44) = .12, p = .88 \).

A MANCOVA including the three cool EF scores (SST total scores, BSCT total correct responses, BSCT perseverative errors) as dependent variables, as well as age as a covariate, resulted in a significant multivariate effect of Group, Wilks' \( \lambda = .77, F(6, 206) = 4.79, p = .001 \). Univariate analyses with post-hoc Tukey tests revealed significant group differences for SST total scores, \( F(2, 105) = 6.69, p = .002 \), and BCST total correct responses, \( F(2, 105) = 8.08, p = .0005 \). In both cases, the ADHD - DBD (SST: \( p = .002, d = .77 \); BCST: \( p = .02, d = .68 \)) and ADHD + DBD (SST: \( p = .02, d = .77 \); BCST: \( p = .0004, d = .90 \)) groups had lower scores than controls, but did not differ from each other (SST \( p = .99, d = .12 \); BCST: \( p = .17, d = .27 \)). The groups did not significantly differ in BCST perseverative responses, \( F(2, 105) = 1.69, p = .19 \). See Table 6.
### Table 6

*Group Differences Across Hot and Cool Executive Function Tasks*

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD) for Each Group</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>ADHD - DBD</td>
<td>ADHD + DBD</td>
<td>Control</td>
<td>F</td>
<td>p</td>
</tr>
<tr>
<td><strong>Hot Executive Functions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Univariate ANCOVA Tests</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DDT k</td>
<td>4.00 (9.82)</td>
<td>1.37(4.57)</td>
<td>1.05(3.56)</td>
<td>1.39</td>
<td>.25</td>
</tr>
<tr>
<td>CIGT Net Scores</td>
<td>.97(19.52)</td>
<td>-1.69(22.30)</td>
<td>-7.07(15.43)</td>
<td>2.14</td>
<td>.12</td>
</tr>
<tr>
<td><strong>Cool Executive Functions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall MANCOVA Test</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wilks λ = .77</td>
<td></td>
<td></td>
<td></td>
<td>4.79</td>
<td>.001</td>
</tr>
<tr>
<td>Univariate ANCOVA Tests</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SST Total Scores</td>
<td>5.80(1.76)</td>
<td>6.06(2.38)</td>
<td>7.13(1.70)</td>
<td>6.69</td>
<td>.002</td>
</tr>
<tr>
<td>BCST Total Correct Responses</td>
<td>36.27(10.45)</td>
<td>33.11(12.46)</td>
<td>43.13(9.59)</td>
<td>8.08</td>
<td>.0005</td>
</tr>
<tr>
<td>BCST Perseverative Errors</td>
<td>11.24(6.78)</td>
<td>8.82(6.42)</td>
<td>9.90(4.29)</td>
<td>1.69</td>
<td>.19</td>
</tr>
</tbody>
</table>

*Note.* DDT = Delay Discounting Task; CIGT = Child Version of the Iowa Gambling Task; SST = Spatial Span Task; BCST = Berg Card Sorting Task. Delay discounting k values were log transformed prior to calculation of ANCOVA.
Secondary Analyses

Examining the Specificity of the Relationship between Executive Function Scores and ADHD Symptom Domains

Significant main effects of group for SST total scores and BCST total correct responses were further explored using two separate regression models which included the number of inattentive symptoms and the number of hyperactive/impulsive symptoms as independent variables, as well as age as a covariate. Results revealed significant main effects of hyperactive/impulsive symptoms for both SST total scores, $F(1, 117) = 4.12, p = .04$ and BCST total correct responses, $F(1, 113) = 5.32, p = .02$. In both cases, higher numbers of hyperactive/impulsive symptoms were associated with lower scores. The main effects of inattentive symptoms were not significant for SST total scores, $F(1, 117) = 2.61, p = .11$, or BCST total correct responses, $F(1, 113) = 1.82, p = .18$.

Group Differences Controlling for IQ

When the cool EF MANCOVA was recalculated with the additional IQ covariate, results indicated a significant multivariate main effect of Group, Wilks' $\lambda = .84, F(6, 204) = 3.20, p = .005$. Similar to analyses including only age as a covariate, univariate analyses revealed significant Group effects for SST total scores, $F(2, 104) = 3.69, p = .03$, and BCST total correct responses, $F(2, 104) = 4.95, p = .009$. The ADHD - DBD group had lower SST total scores than the controls ($p = .02$). Differences between the ADHD + DBD and control groups ($p = .17$) and between the ADHD - DBD and ADHD + DBD groups were not significant ($p = .91$). On the BCST, the ADHD + DBD group answered fewer trials correctly than the controls ($p = .007$). The ADHD - DBD group answered marginally fewer correct trials when compared with controls ($p = .07$). The ADHD - DBD and ADHD + DBD groups did not significantly differ on BCST correct
trials \((p = .25)\). The Group effect for BCST perseverative responses also was not significant, \(F(2, 104) = 1.68, p = .19\).

**Group Differences Controlling for Reading and Math Academic Achievement Scores**

When the cool EF MANCOVA was recalculated with reading and math achievement scores as additional covariates, results showed a multivariate effect of Group that trended towards significance, Wilks' \(\lambda = .89\), \(F(6, 202) = 2.03, p = .06\). Univariate analyses indicated a marginally significant Group effect for SST total scores, \(F(2, 103) = 2.99, p = .05\). The ADHD - DBD group had lower scores than controls \((p = .04)\). Differences between the ADHD + DBD and control groups \((p = .29)\) and between the ADHD - DBD and ADHD + DBD groups \((p = .85)\) were not significant. The Group effects for BCST total correct responses, \(F(2, 103) = 1.75, p = .18\), and BCST perseverative errors, \(F(2, 103) = 1.40, p = .25\), were not significant.

**Does ADHD Subtype Moderate the Relationship Between Comorbid DBDs and EF Scores?**

Two ANCOVAs were conducted with only the two ADHD groups. The main effects of ADHD subtype, presence/absence of DBD, and ADHD subtype*DBD were examined, after controlling for age. The main effects of ADHD subtype, \(F(1, 72) = .66, p = .42\), DBD, \(F(1, 72) = .08, p = .77\), and the ADHD subtype*DBD interaction, \(F(1, 72) = .95, p = .33\), were not significant for transformed DDT \(k\) values. The main effects of ADHD subtype, \(F(1, 89) = .00, p = .96\), DBD, \(F(1, 89) = 1.68, p = .20\), and ADHD subtype*DBD interaction, \(F(1, 89) = 2.48, p = .12\), were also not significant for CIGT net scores.

A similar MANCOVA controlling for age was used to examine ADHD subtype as a moderator of the relationship between comorbid DBDs and cool EF scores. Results indicated that the multivariate main effects of ADHD subtype, Wilks' \(\lambda = .93\), \(F(3, 72) = 1.88, p = .15\), DBD,
Wilks' $\lambda = .96$, $F(3, 72) = .97$, $p = .41$, and ADHD subtype*DBD interaction, Wilks' $\lambda = 0.96$, $F(3, 72) = 1.02$, $p = .39$, were not significant.

**Continuous Relationship between ADHD Symptoms, DBD Symptoms, and EF Scores**

Five separate regressions were conducted with each EF scores as a dependent variable. Each model included the number of ADHD symptoms and the number of ODD symptoms as independent variables, the interaction between ADHD symptoms and ODD symptoms, and age as a covariate. Regarding hot EF analyses, the main effects of ADHD symptoms, $F(1, 99) = 2.08$, $p = .15$, ODD symptoms, $F(1, 99) = 2.58$, $p = .11$, as well as the ADHD symptoms*ODD symptoms interaction, $F(1, 99) = 2.84$, $p = .09$, were not significant for transformed DDT $k$ values. The main effects of ADHD symptoms, $F(1, 119) = 2.82$, $p = .10$, ODD symptoms, $F(1, 119) = 2.26$, $p = .14$, as well as the ADHD symptoms*ODD symptoms interaction, $F(1, 119) = 2.89$, $p = .09$, were also not significant for CIGT net scores.

Cool EF regression analyses resulted in significant associations between the number of ADHD symptoms and SST total scores, $F(1, 116) = 10.45$, $p = .002$, and the number of ADHD symptoms and BCST total correct responses, $F(1, 112) = 8.65$, $p = .004$. A higher number of ADHD symptoms were associated with lower scores on the SST and fewer correct responses on the BCST. ADHD symptoms were not significantly associated with BCST perseverative errors, $F(1, 112) = 0.37$, $p = .54$. The main effects of ODD symptoms, $F(1, 116) = .06$, $p = .80$, $F(1, 112) = .08$, $p = .78$, $F(1, 112) = .43$, $p = .51$, and the ADHD symptoms*ODD symptoms interactions, $F(1, 116) = .25$, $p = .62$, $F(1, 112) = .01$, $p = .91$, $F(1, 112) = 1.20$, $p = .28$, were not significant for SST total scores, BCST total correct responses, or BCST perseverative errors, respectively.

**Discussion**

Consistent with our hypotheses, both ADHD groups (ADHD + DBD, ADHD - DBD)
performed more poorly on measures of cool EF (SST total scores and BCST correct trials) than controls, but did not differ from each other. No significant differences between the two ADHD groups or between the ADHD and control groups were observed for performance on either of the two hot EF measures. When using continuous measures of ADHD and ODD symptoms rather than diagnostic categories, results remained consistent with those from our primary analyses. Cool EF scores were significantly associated with the number of ADHD symptoms, but not ODD symptoms. Hot EF scores were not significantly associated with ADHD or ODD symptoms.

**Group Differences in Cool Executive Functions**

On cool EF tasks, having a diagnosis of ADHD predicted poorer performance. However, the presence of a comorbid ODD diagnosis was not significantly related to additional decrements in cool EF scores. These findings are similar to prior research indicating that ADHD is associated with deficits in cool EFs. Indeed, multiple studies have shown that children with ADHD obtain lower scores on visuospatial working memory tasks, including spatial span tasks (e.g., Gau & Shang, 2010), when compared with typically-developing controls (see Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005 for a review). There is also research suggesting that individuals with ADHD answer fewer trials correctly than typically-developing controls on the Wisconsin Card Sorting Test (see Romine et al., 2004 for a review).

This study's cool EF findings are also consistent with studies showing that comorbid DBDs or DBD symptoms are not significantly associated with additional cool EF deficits in children with ADHD. For example, Thorell and Wahlstedt (2006) found significant relationships between ADHD symptoms and performance on a computerized measure of spatial working memory similar to this study's task in a population-based sample of young children. ODD
symptoms and the interaction between ADHD and ODD symptoms, though, were not significantly associated with performance on their task. In addition to Thorell and Wahlstedt's (2006) study, other researchers using different types of tasks have found that comorbid ODD/CD is not associated with poorer working memory performance in school-aged children with ADHD. For example, Oosterlaan, Scheres, and Sergeant (2005) found that children with ADHD and ADHD + ODD/CD committed significantly more errors than children without ADHD (controls and children with only ODD/CD) on the Self-Ordered Pointing Task, a nonverbal working memory task. The presence of ODD/CD, however, was not related to greater impairments in performance. Similarly, Kalff and colleagues (2002) found that children with ADHD and ADHD + ODD/CD performed significantly worse than controls and those with only ODD/CD on the Word Order Test of the K-ABC, a task that requires participants to point to increasing sequences of pictures corresponding to the order of objects that are named aloud. The ADHD and ADHD + ODD/CD groups, however, did not significantly differ from each other.

In relation to this study's BCST results, there are very few studies in the literature examining the association between ADHD and comorbid disorders on card sorting performance indices. However, Klorman et al. (1999) found that children with ADHD made more non-perseverative errors than controls on the Wisconsin Card Sorting Test. This finding was driven primarily by children with ADHD-C, who made significantly more errors than participants with ADHD-I, and marginally more errors than controls. ODD was not significantly associated with non-perseverative errors. In addition, neither ADHD nor ODD was significantly associated with perseverative errors. In sum, cool EF results from this study are consistent with other studies in the literature and suggest that ADHD, irrespective of comorbid DBDs, is associated with deficits in cool EFs.
Group Differences in Hot Executive Functions

Turning to hot EFs, the presence of a comorbid DBD was expected to account for deficits in children with ADHD. Therefore, when comparing the ADHD - DBD and control groups, significant differences in hot EF task performance were not anticipated. Indeed, our non-significant findings between these two groups were consistent with our hypotheses. That being said, these results contradict some of the previous research examining hot EF performance in children with ADHD, particularly studies that have focused on delay discounting. For example, using the same DD task that this study used and controlling for comorbid ODD, Wilson et al. (2011) found significantly larger k values (i.e., steeper discounting) in 7-9 year-old children with ADHD compared with controls. Other studies, too, have found that children and adolescents with ADHD discount more steeply than children without ADHD (e.g., Barkley et al., 2001; Demurie, Roeyers, Baeyens, Sonuga-Barke, 2012; Scheres, Tontsch, Thoeny, & Kaczkurkin, 2010). Those by Demurie et al. (2012) and Scheres et al. (2010) did not control for the presence of comorbid DBDs, which potentially may have influenced results. It is unclear, however, why studies by Wilson et al. (2011) and Barkley et al. (2001) found significant effects of ADHD on delay discounting and this study did not.

Regarding gambling tasks, findings from studies examining differences between children with and without ADHD are inconsistent. Similar to results from this study, some studies have not found significant group differences in gambling performance. For example, Geurts et al. (2006) examined differences in 8-12 year old children with and without ADHD on the hungry donkey task, a computerized gambling task for children, but did not find significant between-groups differences in net scores. In addition, Skogi et al. (in press) used this same task (i.e., hungry donkey task) to examine performance between 8-17 year old children with and without
ADHD and did not find significant between-groups differences. Both studies used diagnostic criteria from semi-structured interviews similar to this study's, as well as relatively similar computerized gambling tasks. Skogli et al. controlled for ODD symptoms, but Guerts et al. did not. In contrast to the null results of these two studies, Garon et al. (2006) used an uncomputerized version of the gambling task used in this study and found that children with ADHD (controlling for ODD symptoms) had lower net scores than controls. Participants in their study were similar in age range (6-13 years old) to the participants in this study (7-12 years old). However, unlike this study's participants, as well as those in the studies by Guerts et al. and Skokli et al., children recruited by Garon et al. earned rewards based on their gambling test scores. Thus, there was an external motivator linked to the task that may have motivated children in the ADHD - DBD group to make riskier decisions.

While a difference between the ADHD - DBD and control groups on hot EF tasks was not anticipated, it was expected that children in the ADHD + DBD group would have lower net scores and higher k values on the gambling and delay discounting tasks, respectively, than both the ADHD and control groups. In contrast with these hypotheses, there were no significant differences between the ADHD + DBD and ADHD - DBD groups in performance on either task. No studies to date have been conducted to specifically examine the impact of comorbid ODD or CD on delay discounting in individuals with ADHD, although studies controlling for comorbid ODD have not found that it significantly contributes to discounting in children and adolescents with ADHD (e.g., Barkley et al., 2001; Wilson et al., 2011).

This study's lack of group differences in net scores on our gambling task was inconsistent with several studies in the literature showing that comorbid ODD and/or CD are associated with
poorer performance on risky decision tasks in individuals with ADHD (e.g., gambling tasks, BART; Fischer, Barkley, Smallish, & Fletcher, 2005; Hobson, Scott, & Rubia, 2011; Humphreys & Lee, 2011). For instance, Hobson et al. (2011) examined Iowa Gambling Task performance in adolescents with ODD/CD, ADHD ± ODD/CD, and typically-developing controls that were told they would receive monetary rewards based on their gambling scores. In their analyses, ODD/CD symptoms, but not ADHD symptoms, were independently and negatively associated with gambling performance. Fischer et al. (2005) examined 19-25 year olds who had been diagnosed with 'hyperactivity' and studied since they were between 4 and 12 years old. Participants who met criteria for CD at the follow-up time point chose to play more cards during a gambling task than participants without CD. In contrast with these studies by Hobson et al. (2011) and Fischer et al. (2005), Humphreys and Lee (2011) examined the performance of school-aged children on the BART and found that children with ADHD + ODD showed the greatest risk taking, when compared with children with ODD only, children with ADHD - ODD, and controls.

Based on the methods of these three studies, there are several potential explanations for the lack of findings between the ADHD + DBD and ADHD - DBD groups in the current study. First, despite the DDT and CIGT being designed to elicit hot aspects of cognition through the use of points (i.e., bears and tigers) and monetary stimuli, participants may not have actually utilized hot EFs during task performance. In other words, the hot EF tasks included in the current study may not have been measuring hot EF performance as intended. This may be due, in part, to a lack of motivational salience in the hot EF task stimuli. Indeed, unlike the study by Hobson, Scott, and Rubia (2011), as well as studies focused just on children with ADHD and controls (e.g., Garon et al., 2006) neither of the hot EF tasks had tangible rewards (money, points for
prizes, etc.) linked to performance. Thus, rewards related to task performance may have increased the tasks' emotional salience and motivated participants in the ADHD + DBD group to make riskier choices, thus capturing underlying deficits in hot EFs.

Alternatively, the current study's sample may have been too young to understand the hot EF tasks. Both tasks were chosen to be developmentally appropriate for 7-12 year olds; both have been used in other studies with children in the same age range. Age was also included as a covariate in all analyses, to account for differences in functioning across the participants' age range. However, it is possible that multiple children in all three groups had difficulty understanding the hot tasks and monitoring their performance across trials. Indeed, very low gambling scores across all three groups indicate that children with each diagnosis had difficulty consistently choosing advantageous cards more often than disadvantageous cards. Thus, low scores suggest that the task may have been measuring whether children understood what they were supposed to be doing rather than their affinity for risky decision making. Other studies examining hot EFs in school-age children have found that participants across groups (i.e., with and without ADHD) choose correct answers in gambling tasks at chance levels, suggesting that children may have difficulty understanding this kind of task, even when simplified (e.g., Skogli et al., in press). In addition, two of the studies that have found significant effects of ODD and/or CD (i.e., Fischer et al., 2005; Hobson et al., 2011) have included adolescents and young adult participants, who may be more likely to understand risky decision making tasks.

In addition, the non-significant effect of comorbid DBDs (ADHD +DBD vs. ADHD -DBD) may have been due to the composition of DBDs in the ADHD + DBD group. Hot executive dysfunction might be more prominent in CD than ODD. Thus, in contrast with the study by Fischer et al. (2005), this study may have been less likely to identify deficits in the
comorbid group, given that all but one of the participants in the ADHD + DBD group had ODD, not CD. Furthermore, only a subset of children with ODD later develops CD (Biederman et al., 1996). Due to the recruiting methods used for this study, the majority of children with ODD in this study may not have been children at risk for CD and, thus, less likely to show deficits in hot EFs. In fact, all children with ADHD, including those with comorbid DBD, were recruited from an outpatient clinic that specializes in the diagnosis and behavioral treatment of ADHD. Although many children evaluated in this clinic receive diagnoses of comorbid DBD, most are not referred due to a primary concern with oppositional or conduct behaviors. Thus, results may not generalize to a wider population of children with DBD who have more severe defiant, conduct, delinquent, or antisocial symptoms.

Lastly, with regard to study limitations, children taking psychostimulants or any other psychiatric medications were excluded from study participation. By excluding children on medications, this study may have included a sample of children with less severe symptoms. Therefore, results may not completely generalize to all children with ADHD.

Overall, the goal of this study's primary analyses was to better understand how comorbid DBDs contribute to EF deficits in children with ADHD. Given the non-significant group differences in hot EF performance between the ADHD + DBD and ADHD - DBD groups, results do not support the notion that comorbid DBDs account for heterogeneity in EFs across children with ADHD (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Thus, the reason for differences in patterns of EF deficits across children with ADHD remains unclear. However, there are a variety of other factors that could potentially explain the heterogeneity in EF performance deficits that has been observed in this population. Genetic variability, for instance, could moderate EF deficits. Indeed, genetic studies support the notion that ADHD is linked to a
variety of genetic loci (e.g., Arcos-Burgos, et al., 2004; Fischer et al., 2002), which may be related to different aspects of EF (Doyle et al., 2008). Underlying variability in brain structure and function could also account for different patterns of EF performance across children with ADHD. A variety of brain regions have been implicated in ADHD, including the prefrontal cortex, basal ganglia, cerebellum, and anterior cingulate cortex, and there is some evidence to suggest relations between specific brain abnormalities and neurocognitive performance (e.g., Casey et al., 1997). Thus, variability in brain structures or circuits might underlie the variability in executive deficits seen across different individuals with ADHD. Furthermore, the degree of a family history of ADHD may also be related to deficits in EF performance (e.g., Crosbie & Schachar, 2001).

The fact that ADHD, in addition to DBDs, was not associated with deficits in hot EFs is also interesting, given the studies that have found ADHD-related performance differences (e.g., Wilson et al., 2011) on hot EF tasks. Based on the findings from this study, it would seem plausible that hot EF deficits are not a hallmark characteristic of ADHD. Such a conclusion would be inconsistent with the dual-pathway model of ADHD that Sonuga-Barke and colleagues have constructed, which suggests that ADHD (regardless of comorbidity) may result from deficits in response inhibition (i.e., cool EF deficit) or delay aversion (i.e., hot EF deficit). Indeed, findings from select studies that have examined both hot and cool measures of EF (e.g., Solanto et al., 2001, Yang et al., 2011) have shown that children with ADHD can have deficits in hot and/or cool EFs, thus lending support to such a model. Thus, it is possible that the majority of participants in this study's sample just had deficits in cool EFs rather than hot EFs, leading to the null hot EF results. Interestingly, results by Solanto et al. and Yang et al. showed group differences (ADHD vs. controls) on Choice Delay tasks that required participants to wait for
points. In both studies, children with ADHD chose the stimuli that provided fewer points after shorter delays, more often than controls. Therefore, even if comorbid DBDs are not linked to increased hot EF deficits in children with ADHD, the strongest hot EF deficit in children with ADHD may be 'delay aversion' (as opposed to risky decision making or delay discounting). Because participants did not have to actually wait for points during the gambling task, or wait for the money they choose during the delay discounting task, the tasks utilized in this study may have focused on constructs other than delay aversion.

**Effects of IQ and Academic Achievement**

 Turning to secondary analyses, this study examined group differences in cool and hot EFs after controlling for IQ and after controlling for reading and math achievement scores. When controlling for IQ, the difference between the ADHD + DBD and control groups was no longer significant for performance on the SST. In addition, the difference between the ADHD - DBD and control groups on the BCST became marginally significant ($p = .07$). When controlling for academic achievement, again, the difference between the ADHD + DBD and control groups was no longer significant for performance on the SST. The differences between the ADHD - DBD and control groups, and the ADHD + DBD and control groups were also no longer significant on the BCST.

In the case of this study's samples, both ADHD groups had IQ and achievement scores that were well within age expectation (i.e., within one standard deviation of the mean). However, control participants had significantly higher scores in these domains. Thus, due to the relationships between EF and IQ and EF and achievement scores, controlling for these variables (which differed between controls and ADHD participant) likely accounted for a large portion of the variance attributable to EF scores. The changes in the findings that resulted from the addition
of these covariates may also be related to variable overlap and/or decreased power to detect these effects.

**Moderating Effects of ADHD Subtype**

Along with examining IQ and achievement scores as covariates, secondary analyses examining whether ADHD subtype moderated the relationship between EF performance and presence of a DBD were conducted. Results indicated that neither the main effect of subtype nor DBD was significant for hot or cool EF scores. The subtype*DBD interactions was also non-significant for both aspects of EF. These non-significant main effects of subtype are consistent with various studies that have not found significant differences between ADHD subtypes in cool EFs (e.g., Wilcutt et al., 2005). Interestingly, however, at a symptom level across all participants (including controls), hyperactive/impulsive symptoms were negatively associated with cool EF performance indicators, indicating that greater impulsivity is associated with lower performance on the SST and BCST.

Few studies have examined hot EFs across ADHD subtypes, although a recent study by Skogli et al. (in press) did not find significant differences between ADHD subtypes on a computerized gambling task. Wilson et al. (2011) did not have the power to find significant subtype differences in discounting gradients (k) on the DDT, but did find a significant positive relationship between inattentive symptoms and k values, when controlling for hyperactive/impulsive symptoms, indicating that children with either ADHD-I or ADHD-C could show impairments in delay discounting. Demurie et al. (2012), too, did not find significant differences in discounting across ADHD subtype. In contrast, Scheres, Tontsch, Theony, and Kaczkurkin (2010) found significant positive relationships between discounting gradients and hyperactive/impulsive symptoms and showed that children with ADHD-C, but not ADHD-I
discount more steeply than typically-developing controls. Regarding the moderating effect of ADHD subtype on the relationship between comorbid DBDs and EF performance, there is also little data. However, Klorman et al. (1999) did not find differences between children with ADHD-I + ODD and children with ADHD-C + ODD in performance on the Wisconsin Card Sorting Test. Studies that have focused on the effects of comorbid DBDs on hot EF performance in individuals with ADHD (e.g., Fischer et al., 2005; Hobson et al., 2011; Humphreys et al., 2011) have not examined ADHD subtype as a moderator. Given the small proportion of participants with ADHD-I (24%) in this study's ADHD + DBD group, which negatively impacted power to detect differences, more research is needed to understand hot EF performance in children with different ADHD subtypes and comorbid DBDs.

Limitations and Future Directions

In addition to the potential task and diagnostic limitations discussed above, there are several additional methodological limitations of this study that may have impacted the ability to fully understand the relationship between EF performance, ADHD, and DBDs. For example, the unbalanced percentages of children with ODD and CD in the ADHD + DBD group precluded secondary analyses to compare the effects of comorbid ODD versus comorbid CD. In addition, there are specific affective states that were not induced by this study's tasks. Performance on tasks designed to induce frustration (e.g., paced auditory serial addition task; PASAT) or illicit specific emotions (e.g., emotional go/no-go tasks, emotional stroop tasks) may have differed between children with ADHD and children with ADHD+DBD or between the two ADHD groups and controls. Lastly, had fMRI data been collected, this study may have found differences in patterns of brain activation between the ADHD - DBD and ADHD + DBD groups. For example, children in the ADHD + DBD group may have evidenced a reduction in activation of
the orbitofrontal cortex compared with the ADHD-DBD and control groups during hot EF tasks, similar to results by Rubia et al. (2009) who compared activation in children with ADHD, children with CD, and controls during a rewarded continuous performance task.

Despite these limitations, this study is one of the most comprehensive studies to date examining the associations between comorbid disruptive behavior disorders and hot and cool EFs in children with ADHD. Given some of this study’s limitations, though, continued research in this area will help to determine whether or not DBDs are significantly associated with specific executive deficits in this population of children. For example, future studies should compare executive deficits between children with ADHD, children with ADHD and ODD, and children with ADHD and CD, to better determine the relationship between EFs and different disruptive behavior disorders. Studies should also explore the relationship between SES variables and hot EF task performance. Most studies examining hot EFs in children with ADHD (e.g., Geurts, van der Oord, & Crone, 2006; Hobson, Scott, & Rubia, 2011; Wilson et al., 2011) have not examined the role of SES in hot EF performance. Those that have, including Skogli et al. (in press) and Garon, Moore, and Waschbusch (2006) have not found relationships between mother’s education or income level on gambling performance. However, family income and/or monetary value systems may play a role in the ways in which children make decisions and, therefore, should be investigated more thoroughly in future research. Additional research should also be conducted to examine group differences between children with ADHD and children with ADHD and comorbid disorders across a larger age range (e.g., adolescence). Increased knowledge about hot EF development in these populations, using longitudinal studies, will be helpful in delineating patterns of EF deficits. Furthermore, as alluded to above, the use of additional hot tasks that may be more emotionally salient or more ecologically valid (e.g., tasks with in-session delays or
tangible rewards) will be important. Lastly, including neuroimaging within the methodologies of future studies will be vital for understanding potential differences in brain structures/function that may contribute to executive performance in children with ADHD, with and without comorbid conditions.
References


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