Published in final edited form as:

J Int Neuropsychol Soc. 2015 September ; 21(8): 584–595. doi:10.1017/S1355617715000752.

Hot and Cool Executive Functions in Children with Attention Deficit/Hyperactivity Disorder and Comorbid Oppositional Defiant Disorder

Tanya N. Antonini, Stephen P. Becker, Leanne Tamm, and Jeffery N. Epstein

Cincinnati Children's Hospital Medical Center

Abstract

Objective—While neuropsychological deficits in both “hot” and “cool” executive functions (EFs) have been documented among individuals with attention-deficit/hyperactivity disorder (ADHD), these EF deficits are not universal across all individuals with this diagnosis. One potential moderator of executive dysfunction may be the presence of comorbid oppositional defiant disorder (ODD). This study examined the association between “hot” and “cool” EFs and comorbid ODD in children with ADHD.

Method—Thirty-three children with ADHD and comorbid ODD (ADHD+ODD), 67 with ADHD without ODD (ADHD-ODD), and 30 typically developing controls participated. Children were 7–12 years of age. “Cool” EFs were assessed with a spatial span task and a card sorting test. “Hot” EFs were assessed using a delay discounting task and a gambling task.

Results—ADHD-ODD and ADHD+ODD groups performed more poorly on “cool” EF tasks than controls, but did not differ from each other. Further, the number of ADHD symptoms, but not ODD symptoms, was associated with “cool” EF scores. The three groups did not differ on “hot” EF tasks and the number of ADHD or ODD symptoms was unrelated to “hot” EF scores.

Conclusions—In sum, children with ADHD presented with “cool” EF deficits which appear to be unrelated to ODD comorbidity. However, “hot” EF deficits were not present among children with ADHD, irrespective of comorbid ODD status.

Keywords

ADHD; attention-deficit/hyperactivity disorder; comorbidity; executive functioning; hot executive functions; cool executive functions; oppositional defiant disorder; disruptive behavior disorders

Numerous studies have investigated whether attention-deficit/hyperactivity disorder (ADHD) is associated with specific neuropsychological deficits that might shed light on the etiology of this disorder. This research has primarily focused on ADHD-related deficits in executive functions (EFs; i.e., cognitive functions responsible for maintaining internal goals to perform task-relevant behaviors; Miller & Cohen, 2001; Miyake et al., 2000). EFs can be

Corresponding Author: Jeffery Epstein, Ph.D., Behavioral Medicine and Clinical Psychology, Cincinnati Children's Hospital Medical Center, 3333 Burnet Ave. MLC 10006, Cincinnati, Ohio 45229-3039, Phone: 513-636-8296, FAX: 513-636-0755, jeff.epstein@cchmc.org.

There are no conflicts of interest for any of the contributing authors.

classified under two domains: “cool” or “hot”. “Cool” EFs are non-emotionally laden functions 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 thought to be important for cognition (Zelazo & Mueller, 2011). Tasks such as the Wisconsin Card Sorting Test (WCST), Erickson flanker task, and the Dimensional Card Sort have been described as typical “cool” EF tasks (Zelazo & Carlson, 2012). Additional studies have included nonverbal and verbal working memory tasks such as the self-ordered pointing task and digit spans, to examine “cool” EF performance (Hongwanishkul, Happaney, Lee, & Zelazo, 2005; Prencipe, Kesek, Cohen, Lamm, Lewis, & Zelazo, 2011). Compared with typically-developing controls, children with ADHD are often found to have impairments in “cool” EF functions, including working memory (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005), response inhibition (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005), and planning and problem solving (Kopecky, Chang, Klorman, Thatcher, & Borgstedt, 2005; Romine et al., 2004; Weyandt & Willis, 1994).

In contrast with “cool” EFs, “hot” EFs refer to the cognitive abilities needed for motivationally or emotionally salient decision making and goal setting (Zelazo & Mueller, 2002). Studies examining “hot” EFs typically use gambling, choice delay, delay discounting, or risky choice tasks to obtain measures of decision making within a motivational context (e.g., Garon, Moore, & Waschbush, 2006; Shiels et al., 2009; Solanto et al., 2001; Wilson, Mitchell, Musser Schmitt, & Nigg, 2011; Zelazo & Carlson, 2012). Imaging research suggests that these abilities are subserved by regions distinct from those of “cool” EFs, including the orbitofrontal and ventromedial regions of the prefrontal cortex (OF/VMPFC), which have connections to the amygdala and limbic system implicated in emotional processing (e.g., LeDoux, & Phelps, 2000; Phan, Wager, Taylor, & Liberzon, 2004). In particular, a meta-analysis by Krain and colleagues (Krain, Wilson, Arbuckle, Castellanos, & Milham, 2006) showed distinctions between regions of brain activation associated with risky decision-making as assessed with “hot” EF tasks (e.g., Iowa Gambling Task, Cambridge Risk Task) and non-risky, ambiguous decision-making as assessed with “cool” EF tasks (e.g., card decision task, card-playing task). However, in comparison with “cool” EF deficits, far fewer studies have examined “hot” EF deficits in children with ADHD and results are mixed as to whether children with ADHD are impaired on these “hot” EF tasks in comparison with typically-developing children.

Whether examining “cool” or “hot” EF deficits, it is apparent that not all patients with ADHD exhibit the same pattern of EF deficits (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Investigators have explored a variety of demographic (e.g., gender) and clinical variables (e.g., ADHD subtype) that might identify predictors of neurocognitive deficits in children with ADHD, but, to date, no variable reliably predicts which children with ADHD will present with EF deficits, nor which domain of EF (i.e., “hot” or “cool”) will be impaired in which individuals (e.g., Geurts et al., 2005; Faraone et al., 1998; Nigg, Blaskey, Huang-Pollock, & Rappley, 2002; Seidman et al., 2005).

An understudied variable that could potentially moderate patterns of executive impairment in children with ADHD is comorbidity. Many children with ADHD meet criteria for at least one other psychiatric diagnosis. Oppositional defiant disorder (ODD) is the most common

comorbid disorder in this population, with an estimated 40% of children with ADHD also meeting diagnostic criteria for ODD (Angold, Costello, & Erkanli, 1999; MTA Cooperative Group, 1999). Children with ADHD who have comorbid ODD evidence greater social problems (Becker, Luebke, & Langberg, 2012), increased academic difficulties (Barkley, 1990; Moffitt, 1990), and more negativity in parent-child interactions (Barkley et al., 1991) than children with ADHD alone.

Along with increased functional impairment, comorbid ODD may also be associated with distinctive patterns of cognitive deficits in children with ADHD. ADHD has been associated with increased emotional impulsivity (Barley & Fischer, 2010) and the emotional difficulties often observed in individuals with ADHD are related to the irritable/reaction symptoms of ODD (as opposed to the defiant/vindictive symptoms; Factor et al., 2013). It is possible that increased emotional impulsivity confers a unique association between comorbid ODD and "hot" EF deficits in children with ADHD. Several pieces of evidence support this hypothesis. First, children with ODD perform more poorly than controls on "hot" EF tasks such as computerized gambling tasks (Luman, Sergeant, & Oosterlaan, 2010; Matthys, van Goozen, Snoek, & Van Engeland, 2004). Second, Hobson, Scott, and Rubia (2011) found that ODD/conduct disorder (CD) symptoms, but not ADHD symptoms, were related to poor performance on a "hot" EF task (i.e., Iowa Gambling Task). Finally, a recent study comparing neuropsychological performance on a "hot" EF task (i.e., Balloon Analog Risk Task) found that children with ADHD+ODD displayed riskier behavior than children with ADHD alone (Humphreys & Lee, 2011). However, it is important to note that other studies have not found comorbid ODD to be uniquely related to "hot" EF deficits in children with ADHD. For example, Yang et al. (2011) found that ADHD was associated with both "hot" and "cool" EF deficits after controlling for comorbid diagnoses (including ODD).

Understanding how ODD comorbidity is related to EF performance in children with ADHD is important for understanding the heterogeneity in neurocognitive impairments. In an attempt to better understand these relations, we assessed the performance of children with ADHD without comorbid ODD (ADHD-ODD), children with ADHD and comorbid ODD (ADHD+ODD), and typically-developing controls on "hot" and "cool" neuropsychological tasks. Since ODD does not appear to be related to "cool" EF deficits (Klorman et al., 1999; Oosterlaan, Scheres, & Sergeant, 2005; Sarkis, Sarkis, Marshall, & Archer, 2005; Qian et al., 2010), we hypothesized that both ADHD groups (ADHD+ODD and ADHD-ODD) would exhibit "cool" EF deficits compared with controls, but would not differ from each other. Although mixed findings have been reported regarding "hot" EFs, we hypothesized that the ADHD+ODD group would perform worse on "hot" EF tasks than both the ADHD-ODD group and typically-developing controls which would not differ from each other. To our knowledge, this is the first study to examine both "hot" and "cool" EFs across distinct ADHD-ODD, ADHD+ODD, and control groups.

Method

Participants and Recruitment

Families seeking ADHD evaluations for their 7- to 12-year-old children through a specialty ADHD clinic were invited to participate. See the CONSORT diagram in Figure 1. The final

clinical sample consisted of 100 children with ADHD [67 with ADHD and no ODD (ADHD-ODD) and 33 with ADHD and ODD (ADHD+ODD)]. Thirty typically-developing controls were recruited through advertisements and from a list of families who expressed interest in research participation.

Diagnostic Classification, Inclusion Criteria, and Demographics

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) was administered to parents. Children in both ADHD groups met DSM-IV criteria for ADHD Predominantly Inattentive Type (ADHD-PI, $n=43$) or Combined Type (ADHD-C, $n=57$); see Table 1 for breakdown between the groups with and without ODD. Those in the ADHD+ODD group ($n=33$) met diagnostic criteria for ODD in addition to ADHD. Those in the ADHD-ODD group ($n=67$) were required to have 2 ODD symptoms. Controls did not meet criteria for ADHD or ODD. Children in all three groups were excluded if they met diagnostic criteria for a current mood, conduct, or psychotic disorder. With the exception of specific phobias (1 ADHD-ODD, 1 ADHD+ODD, 0 controls) and separation anxiety disorder (1 ADHD-ODD, 1 ADHD+ODD, 1 control), which tend to be prevalent in the 7–12 year old general population (American Psychiatric Association, 2013), children with anxiety disorders (social anxiety disorder, obsessive compulsive disorder, generalized anxiety disorder, panic disorder, and post-traumatic stress disorder) were also excluded¹. In addition, children were excluded if they had suspected/diagnosed Autism Spectrum Disorder, a medical condition/injury that could affect cognition (e.g., epilepsy), an estimated full scale IQ score below 80 on the Kaufman Brief Intelligence Test-2 (Kaufman & Kaufman, 2004), and/or were currently taking any psychiatric medications (including psychostimulants). See Figure 1.

Groups did not significantly differ in age, gender, or race, but did differ by ADHD subtype, $\chi^2(1)=7.07$, $p<.0001$, and K-BIT Full Scale IQ scores, $F(2,127)=14.67$, $p<.0001$. See Table 1 for information regarding these demographics and group differences.

Procedure and EF Measures

This study was approved by our medical center's Institutional Review Board. All parents provided written informed consent and all children gave their assent. The measures described below were completed during one study visit, within a larger fixed order battery of tasks that took a total of 2–2½ hours. The measures described below were completed during one study visit, within a larger fixed order battery of tasks that took a total of 2–2½ hours. The four EF tasks were spread out across the battery and no two study tasks were administered consecutively. However, the relative order to each other within the battery (from earlier to later in the battery) was Delay Discounting Task, Berg Card Sorting Test, Child Version of the Iowa Gambling Task, and Spatial Span Task.

¹In order to ensure that study findings were not impacted by the inclusion of children with a diagnosis of specific phobia or separation anxiety disorder, all analyses were re-run with these children excluded and results were unchanged.

“Cool” Executive Function Tasks

Computerized Spatial Span Task (SST): A computerized version of the Corsi Block Test (<http://pebl.sourceforge.net/battery.html>) was used to measure spatial WM. The task was administered based on the standardized task procedures developed by Kessels et al. (2000). Nine static squares were presented on the screen. Sequences of squares were lit up one at a time, and participants were instructed to use the computer mouse to click the squares in the same order as they originally lit up on the screen. Beginning with a span length of two squares, two sequences of the same length were presented and then increased by one square. The task was discontinued after two sequences of the same length were answered incorrectly. The duration of this task was approximately five minutes. The Total Score was calculated as the raw number of correctly repeated trials.

Computerized Berg Card Sorting Test: The Berg Card Sorting Test (BCST; Grant & Berg, 1948) measures an individual's ability to form, maintain, and shift cognitive set as well as to inhibit a pre-potent response. Participants in the current study completed an abbreviated computerized and validated version of the BCST (Piper et al., 2012; <http://pebl.sourceforge.net/battery.html>). Sixty-four cards differing by shape, number, or color were presented on the screen one at a time. Participants were asked to match each card to one of four key cards without any explanation of how to do so. The participant received “correct” or “incorrect” feedback after each match. Once the participant successfully matched a set number of cards based on the current matching rule, the rule changed without any notice. The computer randomly selected the order of sorting rules for each participant. The duration of this task was approximately ten minutes. Two BCST scores were calculated: raw total correct responses and total perseverative errors.

“Hot” Executive Function Tasks

Child Version of the Iowa Gambling Task (CIGT): We used a simplified, computerized version of the Iowa Gambling Task (Garon, Moore, & Waschbusch, 2006). Children were presented with four decks of cards and told to select a card from any deck of their choosing. They were told that each card selected would have a number of bears and tigers, and that for each bear, they would earn one point and for each tiger, they would lose one point. Participants were told to earn the most points possible by trying to select cards with more bears than tigers. After a child selected a card, feedback was provided regarding the number of bears and/or tigers on the deck he/she had selected (e.g., “you drew 2 bears and 0 tigers”, or “you drew 2 bears and 13 tigers”). The number of bears ranged from 1 to 2 and tigers from 0 to 13. Unbeknownst to participants, cards in decks A and B had two bears on them, but continually selecting from these decks led to more tigers than bears and a net loss in points. Cards in decks C and D had only one bear on them, but continually selecting from these decks resulted in a net gain in points. One disadvantageous deck and one advantageous deck had frequent losses of points whereas the other two decks had infrequent losses of points. Participants were allowed to select 80 cards from any of the 4 decks. The duration of this task was approximately eight minutes. The net score was calculated by subtracting the total raw number of disadvantageous cards from the total raw number of advantageous card choices $[(C + D) - (A + B)]$; 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 participants to decide how long they are willing to wait for a hypothetical monetary reward. Participants chose between varying small immediate hypothetical rewards and a larger delayed hypothetical reward. The immediate amount varied from \$0–\$10.00 in \$0.50 increments and the delayed amount (always \$10.00) was available after one of four hypothetical delays (7, 30, 90, or 180 days; e.g., \$5 now vs. \$10 in 7 days). The task included 88 trials. The duration of this task was approximately ten minutes. The discounting gradient (rate at which the delayed outcome was discounted) was calculated across trials

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 discounting, which was the unit of measure for subsequent analyses. Larger k values represent steeper discounting gradients (i.e., greater preference for immediate rewards).

In line with Johnson and Bickel (2008), indifference points at each delay were examined for each participant. To identify nonsystematic data for deletion, data points were considered invalid if 1) any indifference point was greater in magnitude than the preceding point by more than 20% of \$10, the largest reward (i.e., >\$2), or 2) if the last indifference point (180 days) was greater than the first. 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 (see Figure 1). Specifically, if a participant had two or more invalid indifference points on the DDT, then all DDT data for that participant were dropped. Additionally, all DDT data were dropped for any participant who had at least one invalid data point *and* poor understanding (e.g., participant did not understand values of money), random responding, or variable attention, as rated by the examiner during the task. In addition, BCST correct trials, BCST perseverative errors, SST total scores, CIGT net scores and DDT k values that were 2 standard deviations above or below the mean were dropped. BCST data from an additional four children were dropped due to poor attention/behavior and/or apparent random responding during the task. In addition to excluded data, a subset was also lost to technical difficulties or incomplete assessments. Among the children with ADHD, those who had excluded/missing data had lower IQ scores than those with a full set of data, $t(97) = -2.13$, $p = .02$. The two groups did not significantly differ in age, gender, ADHD subtype, or ODD status, from those with a full set of data (all $ps > .05$). The three control participants with excluded DDT data did not significantly differ in age or IQ scores from the remaining controls.

Analyses

Primary Analyses—All variables were generally normally distributed except DDT k values, which were corrected with a log transformation. Correlations among the two “hot”

EF scores and among the three “cool” EF scores were also computed to inform how group differences in “hot” and “cool” EF scores would be examined. Group differences in “hot” and “cool” EF scores were examined using multivariate and univariate analyses of covariance using SAS PROC GLM. In each analysis, Group (ADHD+ODD, ADHD-ODD, control) was the independent variable and “hot” or “cool” EF score(s) were 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, despite convincing arguments for not using IQ as a covariate in neurocognitive studies (e.g., Dennis, Francis, Cirino, Schachar, & Fletcher, 2009) ADHD studies often control for IQ. Thus, to compare our results to others who have controlled for IQ when examining EFs in children with ADHD, statistical models with significant effects were recalculated with IQ as a covariate. Secondly, since the two ADHD groups differed in the distribution of ADHD subtype, we explored whether the relationship between ODD and EFs is specific to a particular ADHD subtype. For these analyses, the control group data were dropped, ADHD subtype (ADHD-C or ADHD-PI) and comorbidity status (ODD and no ODD) were included as independent variables, and the ADHD subtype×comorbidity status interaction was examined to determine whether ADHD subtype significantly moderates the relationship between the presence of ODD and EF performance.

Finally, to investigate the continuous relationship between EF and ADHD and ODD symptoms rather than diagnostic categories, separate regression models for each EF score were calculated and the total number of ADHD symptoms and total number of ODD symptoms were added as independent variables. The mean, standard deviation, and range of these symptoms are included in Table 1. The ADHD symptoms×ODD symptoms interaction was examined to determine whether there was a synergistic effect of ADHD and ODD symptoms on EF performance.

Results

Primary Analyses

Correlations—See Table 2 for correlations between age, IQ, and EF scores. Across all participants, age was significantly correlated with SST total scores ($p<.0001$) and BCST total correct responses ($p=.0001$). Similarly, CIGT net scores ($p=.007$) and transformed DDT k values ($p=.004$) were significantly positively and negatively correlated with age, respectively. 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 EF scores, all subsequent analyses examining group differences included age as a covariate.

IQ scores were significantly correlated with SST total scores ($p=.01$) and BCST total correct responses ($p=.02$). However, IQ was not significantly correlated with BCST perseverative errors ($p=.44$), or either of the “hot” EF scores (CIGT net scores: $p=.36$; transformed DDT k values: $p=.29$).

Correlations examining the relationship between the three “cool” EF scores indicated that total scores on the SST were positively associated with BCST total correct responses ($p=.0002$) and perseverative errors ($p=.04$); those with higher WM scores answered more trials correctly on the BCST, but unexpectedly made more perseverative errors. 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 ($p=.26$). Given the significant correlations between the “cool” EF scores, the three “cool” EF scores were included in a single MANCOVA. Given the lack of correlation between the “hot” EF scores, between-groups differences in “hot” EF scores were examined using separate ANCOVAs.

Group Differences—Two ANCOVAs were utilized to examine group differences in the two measures of “hot” EF (i.e., transformed DDT k values, CIGT net scores) controlling for age. See Table 3. The effect of Group was not significant for transformed DDT k values, $F(2,99)=1.50$, $p=.23$, or CIGT net scores, $F(2,119)=2.15$, $p=.12$, indicating that neither of the “hot” EF scores differed significantly across groups. Since younger children may have difficulty understanding 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 to examine group differences in CIGT net scores across the 10–12-year-old participants (41 ADHD-ODD, 15 ADHD+ODD, 18 controls). Even among this older cohort, the three groups did not differ, $F(2,43)=.09$, $p=.91$.

A MANCOVA including the three “cool” EF scores (SST total scores, BSCT total correct responses, BSCT perseverative errors) resulted in a significant multivariate effect of Group, Wilks' $\lambda=.78$, $F(6,204)=4.57$, $p=.0002$. Univariate analyses revealed significant group differences for SST total scores, $F(2,104)=6.56$, $p=.002$, and BCST total correct responses, $F(2,104)=9.19$, $p=.0009$. In both cases, the ADHD-ODD (SST: $p=.002$, $d=.77$; BCST: $p=.01$, $d=.68$) and ADHD+ODD (SST: $p=.03$, $d=.51$; BCST: $p=.0009$, $d=.85$) groups had lower scores than controls, but did not differ from each other (SST $p=.95$, $d=.13$; BCST: $p=.28$, $d=.22$). The main effect of Group was not significant for BCST perseverative responses, $F(2,104)=1.36$, $p=.26$.

Secondary Analyses

Examining the Relationship between EF Scores and ADHD Group Differences on “Cool” EF Scores after Controlling for IQ—When adding IQ as a covariate to the “cool” EF MANCOVA, the main effect of Group remained significant, Wilks' $\lambda=.84$, $F(6,202)=3.10$, $p=.006$. Again, there were significant Group main effects for SST total scores, $F(2,103)=3.77$, $p=.03$, and BCST total correct responses, $F(2,102)=4.79$, $p=.01$. The ADHD-ODD group had lower SST total scores than the controls ($p=.02$). Differences between the ADHD+ODD and control groups ($p=.20$) and between the ADHD-ODD and ADHD+ODD groups were not significant ($p=.85$). On the BCST, the ADHD+ODD group answered fewer trials correctly than the controls ($p=.009$). The ADHD-ODD group answered marginally fewer correct trials when compared with controls ($p=.05$). The ADHD-ODD and ADHD+ODD groups did not significantly differ on BCST correct trials ($p=.36$). The Group effect for BCST perseverative responses also was not significant, $F(2,103)=1.38$, $p=.25$.

Does ADHD Subtype Moderate the Relationship Between Comorbid ODD and EF Scores?—

Two ANCOVAs were used to examine ADHD subtype as a moderator of the relationship between comorbid ODD and “hot” EF scores. The main effects of ADHD subtype, $F(1,71)=.32, p=.57$, ODD, $F(1,71)=.08, p=.78$, and the ADHD subtype $\times$ ODD interaction, $F(1,71)=.69, p=.41$, were not significant for transformed DDT k values. Also, the main effects of ADHD subtype, $F(1,88)=2.03, p=.16$, ODD, $F(1,88)=.00, p=.97$, and ADHD subtype $\times$ ODD interaction, $F(1,88)=2.76, p=.10$, were not significant for CIGT net scores.

A MANCOVA was used to examine ADHD subtype as a moderator of the relationship between comorbid ODD and “cool” EF scores. The main effects of ADHD subtype, Wilks' $\lambda=.95, F(3,71)=1.13, p=.34$, ODD, Wilks' $\lambda=.96, F(3,71)=.99, p=.41$, and the ADHD subtype $\times$ ODD interaction, Wilks' $\lambda=.96, F(3,71)=.75, p=.53$, were not significant for “cool” EF scores.

Continuous Relations between ADHD Symptoms, ODD Symptoms, and EF Scores—

Five separate regressions were conducted with each EF score 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, $F(1,98)=2.02, p=.16$, ODD symptoms, $F(1,98)=2.20, p=.14$, as well as the ADHD symptoms $\times$ ODD symptoms interaction, $F(1,98)=2.22, p=.14$, were not significant for transformed DDT k values. The main effects of ADHD symptoms, $F(1,118)=2.86, p=.09$, ODD symptoms, $F(1,118)=2.42, p=.12$, as well as the ADHD symptoms $\times$ ODD symptoms interaction, $F(1,118)=3.14, p=.08$, 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, $F(1,115)=10.61, p=.002$, and the number of ADHD symptoms and BCST total correct responses, $F(1,111)=9.67, p=.002$. More 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, $F(1,111)=0.30, p=.58$. The main effects of ODD symptoms, $F(1,115)=.03, p=.86$, $F(1,111)=.31, p=.58$, $F(1,111)=.25, p=.62$, and the ADHD symptoms $\times$ ODD symptoms interactions, $F(1,115)=.14, p=.71$, $F(1,111)=.08, p=.78$, $F(1,111)=.74, p=.39$, 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+ODD, ADHD-ODD) performed more poorly on “cool” EF measures (i.e., SST total scores, 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.

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 WM tasks, including spatial span tasks (e.g., Gau & Shang, 2010), when compared with typically-developing controls (e.g., Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005). Research also suggests that individuals with ADHD answer fewer trials correctly than typically-developing controls on the Wisconsin Card Sorting Test (e.g., Romine et al., 2004).

The lack of differences between the ADHD+ODD and ADHD-ODD groups on “cool” EF tasks is also consistent with studies showing that comorbid ODD or ODD symptoms are not significantly associated with “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 WM (similar to this study's task) in a population-based sample of young children, while ODD symptoms and the interaction between ADHD and ODD symptoms were not significantly associated with performance. Similarly, comorbid ODD/CD does not appear to be associated with poorer WM performance in school-aged children with ADHD (Kalff et al., 2002; Oosterlaan, Scheres, & Sergeant, 2005). In sum, “cool” EF results from this study are consistent with other studies and suggest that ADHD is associated with deficits in “cool” EFs, irrespective of comorbid ODD.

Differences in “Hot” Executive Functions

The presence of a comorbid ODD was expected to account for “hot” EF deficits in children with ADHD. Therefore, when comparing the ADHD-ODD 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 and some previous studies (e.g., Guerts et al., 2006; Skogi et al., 2014). Note, however, that other studies have found that children with ADHD do have deficits on similar “hot” EF tasks (e.g., Barkley et al., 2001; Demurie, Roeyers, Baeyens, & Sonuga-Barke, 2012; Scheres, Tontsch, Thoeny, & Kaczurkin, 2010). For example, Wilson et al. (2011) found significantly larger *k* values (i.e., steeper discounting) in 7–9 year-old children with ADHD compared with typically-developing controls. Also, using a gambling task, Garon et al. (2006) reported that children with ADHD demonstrate a riskier pattern of responding than controls. One possible explanation for differences across studies is that some of these studies (e.g., Garon et al., 2006) used external rewards (i.e., tokens to trade for small prizes for performance); our study did not. Our study's lack of an external motivator linked to task performance may have attenuated the propensity for riskier decision making among children with ADHD. Without any subjective report of emotional salience or motivation during task completion, it is unknown whether the two hot EF tasks were motivationally or emotionally salient as

intended. It is unfortunate that we did not collect such self-report ratings as these may have provided insight into the lack of group differences on the EF tasks.

We also expected that children in the ADHD+ODD group would demonstrate “hot” EF deficits (i.e., lower net scores and higher k values on the gambling and delay discounting tasks) when their performance on “hot” tasks was compared with that of the ADHD-ODD group and controls. In contrast with our hypotheses, there were no group differences on either “hot” EF task. While comorbid ODD has not been shown to contribute to poorer performance on a delayed discounting task (e.g., Barkley et al., 2001; Wilson et al., 2011), other research has shown that comorbid ODD is associated with poorer performance on gambling tasks in ADHD (Hobson, Scott, & Rubia, 2011). There are several potential explanations for the lack of differences between the ADHD+ODD, ADHD-ODD, and control groups in the current study. First, as mentioned above, the lack of external motivators (i.e., money as a reward) may have contributed to a lack of motivational salience in the “hot” EF task stimuli and dampened the propensity towards risky decision making. Alternatively, children in this study may have been too young to understand the “hot” EF tasks. Indeed, very low gambling scores across the three groups indicate that children across all groups had difficulty consistently choosing advantageous cards more often than disadvantageous cards. These 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. Another explanation is that “hot” EF deficits are associated with more severe disruptive behavior than ODD. For example, “hot” EF deficits might be more prominent in CD than ODD (Rubia, 2011). Similarly, although related, aggression and CD/ODD are distinct and it may be that reactively aggressive youth are especially prone to displaying “hot” EF deficits (Bobadilla, Wampler, & Taylor, 2012; Scarpa, Haden, & Tanaka, 2010). Thus, by selecting ODD, and not CD or reactive aggression comorbidity, we may have biased our sample towards not having “hot” EF deficits. Furthermore, by recruiting children presenting to an ADHD clinic, and not a disruptive behavior disorders clinic, we likely selected children in the ADHD+ODD group for whom disruptive oppositional and defiant behavior was not the primary presenting problem. Thereby, the ODD among our ADHD+ODD group may have been of lower severity than if we had recruited from another site (i.e., a disruptive behavior disorders clinic). A final explanation is that we did not measure the “hot” EF deficit that may be associated with ODD. “Hot” EF tasks that induce frustration (e.g., paced auditory serial addition task), include emotional stimuli (e.g., emotional go/no-go tasks, emotional Stroop tasks), or assess delay aversion may be more strongly associated with ODD than the tasks we utilized in this study. It is also important to note that tasks purported to be “cool” EF function tasks (e.g., card sorting task) may induce frustration in participants and, thus, inadvertently include an emotional/motivational or “hot” EF component.

Although these considerations temper our ability to draw firm conclusions, our results nonetheless suggest that comorbid ODD does not account for heterogeneity in EFs across children with ADHD (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Thus, moderators of EF deficits among children with ADHD remain unknown. A variety of other factors could potentially explain the heterogeneity in EF performance deficits such as genes

(Arcos-Burgos, et al., 2004; Doyle et al., 2008; Fischer et al., 2002), brain structure and function (e.g., Casey et al., 1997), and family history of ADHD (e.g., Crosbie & Schachar, 2001). Furthermore, our results suggest that “cool” EF deficits may be more related than “hot” EF deficits to the behavioral phenotype of ADHD. Such a conclusion is consistent with Barkley’s (1997, 2010) model, which focuses on deficits in inhibitory control (i.e., “cool” EF) and its link to deficits in working memory, self-regulation, and other areas of difficulty in individuals with ADHD. Our results seem to be inconsistent with dual-pathway models of ADHD (e.g., Sonuga-Barke, 2003) which suggest that the pathway to the ADHD phenotype (regardless of comorbidity) can be either through deficits in response inhibition (i.e., “cool” EF deficit) or delay aversion (i.e., “hot” EF deficit). Indeed, some studies examining both “hot” and “cool” measures of EF in ADHD samples (e.g., Solanto et al., 2001, Yang et al., 2011) have found ADHD-related deficits in both aspects of EF. Moreover, neurobiological models of ADHD posit dysfunction within the cortico-striato-thalamo-cortical loops (e.g., Castellanos, Sonuga-Barke, Milham, & Tannock, 2006) which would seem to affect both “cool” and/or “hot” EF. It is possible that the lack of “hot” EF deficits in our ADHD sample was due to sample selection (i.e., children presenting with primarily ADHD-related complaints may tend to have “cool”, as opposed to “hot” EF deficits). Alternatively, as suggested above, we may have not utilized the right “hot” EF tasks for this age range/population (e.g., Choice Delay Task).

Moderating Effects of ADHD Subtype

ADHD subtype did not moderate the effect of ODD on EF function. That is, the relationship between ODD and “hot” or “cool” EF functioning did not depend on ADHD subtype (i.e., ADHD-C or ADHD-PI). This perhaps is not surprising given that EF performance has not been shown to consistently differ across ADHD subtype (e.g., Willcutt et al., 2005; Skogli et al., 2014; Wilson et al., 2011; Demurie et al., 2012).

Relationship between Executive Functions

Correlational analyses indicated an expected positive relationship between correct responses on the SST and BCST. However, an unexpected positive relationship emerged between BCST perseverative errors and SST correct trials, suggesting that those with better-developed WM made more perseverative errors. This is inconsistent with the results of a small study by Mullane and Corkum (2007) that found a negative correlation between a composite measure of WM and perseverative errors on the WCST in children (ages 6–11) with and without ADHD, although this relationship was fully mediated by age and IQ. Also, a study in typically-developing children did not find a significant correlation between verbal WM performance and perseverative errors on a card sorting task (Bull & Scerif, 2001). Thus, the reason for the negative correlation in our sample is unclear, and should be further investigated. The lack of significant correlation between performance indicators suggests that the CIGT and DDT may be examining different “hot” EFs.

Clinical Implications

Current ADHD guidelines (American Academy of Pediatrics, 2011) rely on observable behavior across settings in the diagnosis of ADHD, rather than neuropsychological test results. However, neuropsychological testing is often completed as part of assessments when

specific comorbid conditions are suspected (e.g., learning disability, medical condition). In addition, there is some evidence that performance on specific EF tasks may predict psychostimulant treatment response (Hale et al., 2011). Within the context of a neuropsychological test battery, poor performance on "cool" measures of EF may be indicative of executive dysfunction often seen in children with ADHD, and thus support a diagnosis. However, results of the present study indicate that the "hot" EF measures used in this study do not predict ADHD diagnostic status. Furthermore, these neuropsychological indicators do not appear to be helpful in detecting comorbid ODD in children with ADHD.

Limitations and Conclusions

In addition to the task limitations noted above, another limitation of this study was the selection of the study sample. We excluded children taking stimulants or any other psychiatric medication from this study, which may have resulted in our study sample having less severe psychopathology. Therefore, results may not generalize to all children with ADHD. In addition, EF tasks were completed in a fixed (rather than counter-balanced) order within a long battery of tests, which may have impacted performance. Nonetheless, our study is the first to include both "hot" and "cool" EF tasks in examining whether comorbid ODD exacerbates the EF of children diagnosed with ADHD. Although replication of our results will be needed before drawing firm conclusions, findings from this study indicate that children with ADHD have "cool" EF deficits that are unaffected by comorbid ODD and challenge the possibility that ADHD (alone or comorbid with ODD) is associated with "hot" EF deficits.

Acknowledgements

The authors thank Megan Narad, Kathleen Kingery, Annie Garner, Abigail Webb, Monika Gaspar, Sarah Brenner, Mary Dobrozi, Anna Bartels, and Anne Brassell for their assistance with data collection. They also thank Nancy Garon and Suzanne Mitchell for generously sharing their gambling and delay discounting tasks. Lastly, they are grateful to Keri Shields for the assistance she provided regarding the management and analysis of delay discounting data. This study was supported by funding from a University of Cincinnati Frakes Research Award to the first author and a grant from the Ohio Department of Mental Health (#12.1281) to the second author.

References

- American Psychiatric Association. Diagnostic and statistical manual of mental disorders. 5th ed.. Washington, DC: Author; 2013.
- American Academy of Pediatrics. ADHD: clinical practice guideline for the diagnosis, evaluation, and treatment of attention-deficit/hyperactivity disorder in children and adolescents. Pediatrics. 2011 peds-2011.
- Angold A, Costello EJ, Erkanli A. Comorbidity. Journal of Child Psychology and Psychiatry. 1999; 40:57–87. [PubMed: 10102726]
- Arcos-Burgos M, Castellanos FX, Pineda D, Lopera F, David Palacio J, Guillermo Palacio L, Muenke M. Attention-deficit/hyperactivity disorder in a population isolate: linkage to loci at 4q13. 2, 5q33. 3, 11q22, and 17p11. The American Journal of Human Genetics. 2004; 75(6):998–1014. [PubMed: 15497111]
- Barkley RA. Behavioral inhibition, sustained attention, and executive functions: constructing a unifying theory of ADHD. Psychological Bulletin. 1997; 121(1):65–94. [PubMed: 9000892]
- Barkley RA. Differential diagnosis of adults with ADHD: the role of executive function and self-regulation. The Journal of Clinical Psychiatry. 2010; 71(7):e17–e17. [PubMed: 20667287]

- Barkley RA, Fischer M. The unique contribution of emotional impulsiveness to impairment in major life activities in hyperactive children as adults. *Journal of the American Academy of Child & Adolescent Psychiatry*. 2010; 49(5):503–513. [PubMed: 20431470]
- Barkley RA, Fischer M, Edelbrock CS, Smallish L. The adolescent outcome of hyperactive children diagnosed by research criteria: I. An 8-year prospective follow-up study. *Journal of the American Academy of Child & Adolescent Psychiatry*. 1990; 29(4):546–557. [PubMed: 2387789]
- Barkley RA, Fischer M, Edelbrock C, Smallish L. The adolescent outcome of hyperactive children diagnosed by research criteria—III. Mother-child interactions, family conflicts and maternal psychopathology. *Journal of Child Psychology and Psychiatry*. 1991; 32(2):233–255. [PubMed: 2033106]
- Barkley RA, Edwards G, Laneri M, Fletcher K, Metevia L. Executive functioning, temporal discounting, and sense of time in adolescents with attention deficit hyperactivity disorder (ADHD) and oppositional defiant disorder (ODD). *Journal of Abnormal Child Psychology*. 2001; 29(6): 541–556. [PubMed: 11761287]
- Becker SP, Luebke AM, Langberg JM. Co-occurring mental health problems and peer functioning among youth with Attention-Deficit/Hyperactivity Disorder: A review and recommendations for future research. *Clinical Child and Family Psychology Review*. 2012; 15:279–302. [PubMed: 22965872]
- Bobadilla L, Wampler M, Taylor J. Proactive and reactive aggression are associated with different physiological and personality profiles. *Journal of Social and Clinical Psychology*. 2012; 31:458–487.
- Bull R, Scerif G. Executive functioning as a predictor of children's mathematics ability: Inhibition, switching, and working memory. *Developmental neuropsychology*. 2001; 19(3):273–293. [PubMed: 11758669]
- Casey BJ, Castellanos FX, Giedd JN, Marsh WL, Hamburger SD, Schubert AB, Rapoport JL. Implication of right frontostriatal circuitry in response inhibition and attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child & Adolescent Psychiatry*. 1997; 36(3):374–383. [PubMed: 9055518]
- Casey BJ, Cohen JD, O'Craven K, Davidson RJ, Irwin W, Nelson CA, Turski PA. Reproducibility of fMRI results across four institutions using a spatial working memory task. *Neuroimage*. 1998; 8(3):249–261. [PubMed: 9758739]
- Castellanos FX, Sonuga-Barke EJ, Milham MP, Tannock R. Characterizing cognition in ADHD: beyond executive dysfunction. *Trends in cognitive sciences*. 2006; 10(3):117–123. [PubMed: 16460990]
- Crosbie J, Schachar R. Deficient inhibition as a marker for familial ADHD. *American Journal of Psychiatry*. 2001; 158(11):1884–1890. [PubMed: 11691696]
- Demurie E, Roeyers H, Baeyens D, Sonuga-Barke E. Temporal discounting of monetary rewards in children and adolescents with ADHD and autism spectrum disorders. *Developmental Science*. 2012; 15(6):791–800. [PubMed: 23106733]
- Dennis M, Francis DJ, Cirino PT, Schachar R, Fletcher JM. Why IQ is not a covariate in cognitive studies of neurodevelopmental disorders. *Journal of the International Neuropsychological Society*. 2009; 15(3):331–343. [PubMed: 19402919]
- Doyle AE, Faraone SV, Seidman LJ, Willcutt EG, Nigg JT, Waldman ID, Biederman J. Are endophenotypes based on measures of executive functions useful for molecular genetic studies of ADHD? *Journal of Child Psychology and Psychiatry*. 2005; 46(7):774–803. [PubMed: 15972070]
- Factor PI, Rosen PJ, Reyes RA. The relation of poor emotional awareness and externalizing behavior among children with ADHD. *Journal of Attention Disorders*. 2013 1087054713494005.
- Faraone SV, Biederman J, Weber W, Russell RL. Psychiatric, neuropsychological, and psychosocial features of DSM-IV subtypes of attention- deficit/hyperactivity disorder: results from a clinically referred sample. *Journal of the American Academy of Child and Adolescent Psychiatry*. 1998; 37:185–193. [PubMed: 9473915]
- Fisher SE, Francks C, McCracken JT, McGough JJ, Marlow AJ, MacPhie IL, Smalley SL. A genomewide scan for loci involved in attention-deficit/hyperactivity disorder. *American Journal of Medical Genetics*. 2002; 70:1183–1196.

- Garon N, Moore C, Waschbusch DA. Decision making in children with ADHD only, ADHD-anxious/depressed, and control children using a child version of the Iowa gambling task. *Journal of Attention Disorders*. 2006; 9(4):607–619. [PubMed: 16648228]
- Gau SS, Shang CY. Executive functions as endophenotypes in ADHD: evidence from the Cambridge Neuropsychological Test Battery (CANTAB). *Journal of Child Psychology and Psychiatry*. 2010; 51(7):838–849. [PubMed: 20085608]
- Geurts HM, Verté S, Oosterlaan J, Roeyers H, Sergeant JA. ADHD subtypes: do they differ in their executive functioning profile? *Archives of Clinical Neuropsychology*. 2005; 20:457–477. [PubMed: 15896560]
- Grant DA, Berg E. A behavioral analysis of degree of reinforcement and ease of shifting to new responses to Weigl-type card-sorting problem. *Journal of Experimental Psychology*. 1948; 38:404–411. [PubMed: 18874598]
- Hale JB, Reddy LA, Semrud-Clikeman M, Hain LA, Whitaker J, Morley J, Jones N. Executive impairment determines ADHD medication response: implications for academic achievement. *Journal of Learning Disabilities*. 2011; 44(2):196–212. [PubMed: 21383110]
- Heaton, RK. WCST-64™: Computer Version 2 Research Edition. Lutz, FL: Psychological Assessment Resources; 2003.
- Hobson CW, Scott S, Rubia K. Investigation of cool and hot executive function in ODD/CD independently of ADHD. *Journal of Child Psychology and Psychiatry*. 2011; 52(10):1035–1043. [PubMed: 21827452]
- Hongwanishkul D, Happaney KR, Lee WS, Zelazo PD. Assessment of hot and cool executive function in young children: Age-related changes and individual differences. *Developmental neuropsychology*. 2005; 28(2):617–644. [PubMed: 16144430]
- Humphreys KL, Lee SS. Risk taking and sensitivity to punishment in children with ADHD, ODD, ADHD+ODD, and controls. *Journal of Psychopathology and Behavioral Assessment*. 2011; 33(3):299–307.
- Kable JW, Glimcher PW. The neural correlates of subjective value during intertemporal choice. *Nature neuroscience*. 2007; 10(12):1625–1633. [PubMed: 17982449]
- Kalff AC, Hendriksen JG, Kroes M, Vles JS, Steyaert J, Feron FJ, Jolles J. Neurocognitive performance of 5-and 6-year-old children who met criteria for attention deficit/hyperactivity disorder at 18 months follow-up: Results from a prospective population study. *Journal of Abnormal Child Psychology*. 2002; 30(6):589–598. [PubMed: 12481973]
- Kaufman J, Birmaher B, Brent D, Rao U, Ryan N. Kiddie Schedule for Affective Disorders and Schizophrenia – Present and Lifetime Version (K-SADS-PL). 1996
- Kaufman, A.; Kaufman, N. Kaufman Brief Intelligence Test-2. Circle Pines MN: AGS; 2004.
- Klorman R, Hazel-Fernandez LA, Shaywitz SE, Fletcher JM, Marchione KE, Holahan JM, Shaywitz BA. Executive functioning deficits in attention-deficit/hyperactivity disorder are independent of oppositional defiant or reading disorder. *Journal of the American Academy of Child & Adolescent Psychiatry*. 1999; 38(9):1148–1155. [PubMed: 10504814]
- Kopecky H, Chang HT, Klorman R, Thatcher JE, Borgstedt AD. Performance and private speech of children with attention-deficit/hyperactivity disorder while taking the tower of hanoi test: Effects of depth of search, diagnostic subtype, and methylphenidate. *Journal of Abnormal Child Psychology*. 2005; 33(5):625–638. [PubMed: 16195955]
- Lawrence NS, Jollant F, O'Daly O, Zelaya F, Phillips ML. Distinct roles of prefrontal cortical subregions in the Iowa Gambling Task. *Cerebral Cortex*. 2009; 19(5):1134–1143. [PubMed: 18787233]
- Li X, Lu ZL, D'Argembeau A, Ng M, Bechara A. The Iowa gambling task in fMRI images. *Human brain mapping*. 2010; 31(3):410–423. [PubMed: 19777556]
- Lie CH, Specht K, Marshall JC, Fink GR. Using fMRI to decompose the neural processes underlying the Wisconsin Card Sorting Test. *Neuroimage*. 2006; 30(3):1038–1049. [PubMed: 16414280]
- Luman M, Sergeant JA, Knol DL, Oosterlaan J. Impaired decision making in oppositional defiant disorder related to altered psychophysiological responses to reinforcement. *Biological Psychiatry*. 2010; 68(4):337–344. [PubMed: 20359697]

- Martinussen R, Hayden J, Hogg-Johnson S, Tannock R. A meta-analysis of working memory impairments in children with attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child and Adolescent Psychiatry*. 2005; 44(4):377–384. [PubMed: 15782085]
- Matthys W, Van Goozen SH, Snoek H, Van Engeland H. Response perseveration and sensitivity to reward and punishment in boys with oppositional defiant disorder. *European Child & Adolescent Psychiatry*. 2004; 13(6):362–364. [PubMed: 15619048]
- Matthys W, van Goozen SH, Vries HD, Cohen-Kettenis PT, Engeland HV. The dominance of behavioural activation over behavioural inhibition in conduct disordered boys with or without attention deficit hyperactivity disorder. *Journal of Child Psychology and Psychiatry*. 1998; 39(5): 643–651. [PubMed: 9690928]
- McClure SM, Laibson DI, Loewenstein G, Cohen JD. Separate neural systems value immediate and delayed monetary rewards. *Science*. 2004; 306(5695):503–507. [PubMed: 15486304]
- Miller EK, Cohen JD. An integrative theory of prefrontal cortex function. *Annual Reviews of Neuroscience*. 2001; 24:167–202.
- Mitchell SH. Measures of impulsivity in cigarette smokers and non-smokers. *Psychopharmacology*. 1999; 146:455–464. [PubMed: 10550496]
- Moffitt TE. Juvenile delinquency and attention deficit disorder: Boys' developmental trajectories from age 3 to age 15. *Child Development*. 1990; 61(3):893–910. [PubMed: 2364762]
- The MTA Cooperative Group. A 14-Month Randomized Clinical Trial of Treatment Strategies for Attention-Deficit/Hyperactivity Disorder. *Archives of General Psychiatry*. 1999; 56(12):1073–1086. [PubMed: 10591283]
- Miyake A, Friedman NP, Emerson MJ, Witzki AH, Howerter A, Wager TD. The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology*. 2000; 41(1):49–100. [PubMed: 10945922]
- Mullane JC, Corkum PV. The relationship between working memory, inhibition, and performance on the Wisconsin Card Sorting Test in children with and without ADHD. *Journal of Psychoeducational Assessment*. 2007
- Nigg JT, Blaskey LG, Huang-Pollock CL, Rapapley MD. Neuropsychological executive functions and DSM-IV ADHD subtypes. *Journal of the American Academy of Child and Adolescent Psychiatry*. 2002; 41(1):59–66. [PubMed: 11800208]
- Nyhus E, Barcelo F. The Wisconsin Card Sorting Test and the cognitive assessment of prefrontal executive functions: A critical update. *Brain and Cognition*. 2009; 71:437–451. [PubMed: 19375839]
- Oosterlaan J, Scheres A, Sergeant JA. Which executive functioning deficits are associated with AD/HD, ODD/CD and comorbid AD/HD+ ODD/CD? *Journal of Abnormal Child Psychology*. 2005; 33(1):69–85. [PubMed: 15759592]
- Piper BJ, Li V, Eiwaz MA, Kobel YV, Benice TS, Chu AM, Mueller ST. Executive function on the psychology experiment building language tests. *Behavior Research Methods*. 2012; 44(1):110–123. [PubMed: 21534005]
- Prencipe A, Kesek A, Cohen J, Lamm C, Lewis MD, Zelazo PD. Development of hot and cool executive function during the transition to adolescence. *Journal of Experimental Child Psychology*. 2011; 108(3):621–637. [PubMed: 21044790]
- Qian Y, Shuai L, Cao Q, Chan RC, Wang Y. Do executive function deficits differentiate between children with attention deficit hyperactivity disorder (ADHD) and ADHD comorbid with oppositional defiant disorder? A cross-cultural study using performance-based tests and the behavior rating inventory of executive function. *Clinical Neuropsychology*. 2010; 24(5):793–781.
- Romine CB, Lee D, Wolfe ME, Homack S, George C, Riccio CA. Wisconsin card sorting test with children: a meta-analytic study of sensitivity and specificity. *Archives of Clinical Neuropsychology*. 2004; 19(8):1027–1041. [PubMed: 15533695]
- Rubia K. “Cool” inferior frontostriatal dysfunction in Attention-Deficit/Hyperactivity Disorder versus “hot” ventromedial orbitofrontal-limbic dysfunction in conduct disorder: A review. *Biological Psychiatry*. 2011; 69:e69–e87. [PubMed: 21094938]

- Sarkis SM, Sarkis EH, Marshall D, Archer J. Self-regulation and inhibition in comorbid ADHD children: An evaluation of executive functions. *Journal of Attention Disorders*. 2005; 8(3):96–108. [PubMed: 16009658]
- Scarpa A, Haden SC, Tanaka A. Being hot-tempered: Autonomic, emotional, and behavioral distinctions between childhood reactive and proactive aggression. *Biological Psychiatry*. 2010; 84:488–496.
- Scheres A, Tontsch C, Thoeny AL, Kaczurkin A. Temporal reward discounting in attention-deficit/hyperactivity disorder: the contribution of symptom domains, reward magnitude, and session length. *Biological psychiatry*. 2010; 67(7):641–648. [PubMed: 20034616]
- Seidman LJ, Biederman J, Monuteaux MC, Valera E, Doyle AE, Faraone SV. Impact of gender and age on executive functioning: do girls and boys with and without attention deficit hyperactivity disorder differ neuropsychologically in preteen and teenage years? *Developmental Neuropsychology*. 2005; 27(1):79–105. [PubMed: 15737943]
- Skogli EW, Egeland J, Andersen PN, Hovik KT, Øie M. Few differences in hot and cool executive functions in children and adolescents with combined and inattentive subtypes of ADHD. *Child Neuropsychology*. 2014; 20:162–181. [PubMed: 23281923]
- Solanto MV, Abikoff H, Sonuga-Barke E, Schachar R, Logan GD, Wigal T, Turkel E. The ecological validity of delay aversion and response inhibition as measures of impulsivity in AD/HD: A supplement to the NIMH multimodal treatment study of AD/HD. *Journal of Abnormal Child Psychology*. 2001; 29:215–228. [PubMed: 11411784]
- Sonuga-Barke EJ. The dual pathway model of AD/HD: an elaboration of neuro- developmental characteristics. *Neuroscience & Biobehavioral Reviews*. 2003; 27(7):593–604. [PubMed: 14624804]
- Thorell LB, Wåhlstedt C. Executive functioning deficits in relation to symptoms of ADHD and/or ODD in preschool children. *Infant and Child Development*. 2006; 15(5):503–518.
- Toplak ME, Jain U, Tannock R. Executive and motivational processes in adolescents with Attention-Deficit-Hyperactivity Disorder (ADHD). *Behavioral and Brain Functions*. 2005; 1(1):8. [PubMed: 15982413]
- Weyandt LL, Willis WG. Executive functions in school-aged children: Potential efficacy of tasks in discriminating clinical groups. *Developmental Neuropsychology*. 1994; 10(1):27–38.
- Willcutt EG, Doyle AE, Nigg JT, Faraone SV, Pennington BF. A meta-analytic review of the executive function theory of ADHD. *Biological Psychiatry*. 2005; 57:1336–1346. [PubMed: 15950006]
- Wilson VB, Mitchell SH, Musser ED, Schmitt CF, Nigg JT. Delay discounting of reward in ADHD: Application in young children. *Journal of Child Psychology and Psychiatry*. 2011; 52(3):256–264. [PubMed: 21083561]
- Yang BR, Chan RCK, Gracia N, Cao XY, Zou XB, Jing J, Shum D. Cool and hot executive functions in medication-naïve attention deficit hyperactivity disorder children. *Psychological Medicine*. 2011; 41(12):2593–2602. [PubMed: 21733213]
- Zelazo PD, Carlson SM. Hot and cool executive function in childhood and adolescence: Development and plasticity. *Child Development Perspectives*. 2012; 6:354–360.
- Zelazo, PD.; Müller, U. Executive function in typical and atypical development. In: Goswami, U., editor. *The Wiley-Blackwell Handbook of Childhood Cognitive Development*. 2nd ed.. Oxford: Wiley-Blackwell; 2011.

Figure 1.

CONSORT Flow Diagram for Participant Recruitment, Participation, and Eligibility

Note.^a Children with an anxiety disorder were excluded with the exception of separation anxiety disorder and specific phobia (see text for more detail).

Table 1**Participant Demographics by Group**

	ADHD – ODD	ADHD + ODD	Control	
	(n = 67)	(n = 33)	(n = 30)	Comparisons^a
Age: mean (SD)	8.88 (1.48)	9.44 (1.75)	9.00 (1.80)	ns
Gender: male n (%)	50 (75.76)	24 (72.72)	20 (66.67)	ns
Race/Ethnicity: n (%)				
White/Caucasian	50 (74.63)	24 (72.73)	26 (86.67)	ns (proportion of White/Caucasians vs. non-White/Caucasians)
Black/African American	13 (19.40)	7 (21.21)	2 (6.67)	
Hispanic/Latino	3 (4.47)	1 (3.03)	1 (3.33)	
Asian	1 (1.49)	1 (3.03)	1 (3.33)	
Subtype Classification: n (%)				
ADHD-C	32 (47.76)	25 (75.76)	n/a	ADHD-PI in ADHD+ODD group < ADHD-ODD group
ADHD-PI	35 (52.24)	8 (24.24)	n/a	
Symptoms: mean (SD) [range]				
Inattentive	7.70(1.06) [6–9]	7.97(1.16) [6–9]	.07(.25) [0–1]	ADHD + ODD = ADHD-ODD > Controls
Hyperactive/Impulsive	4.67(2.80) [0–9]	6.39(2.41) [0–9]	.20(.55) [0–2]	ADHD + ODD > ADHD-ODD > Controls
Oppositional Defiant	.55(.79) [0–2]	5.21(1.19) [4–7]	.07(.37) [0–2]	ADHD + ODD > ADHD-ODD > Controls
K-BIT 2 Full Scale IQ: mean (SD)	104.51 (12.03)	101.88 (12.67)	116.77 (10.47)	ADHD + ODD = ADHD-ODD < Controls

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.

^a Alpha level of $p < .05$.

Table 2

Pearson Correlation Coefficients for Age, IQ, and Executive Function Scores

	1	2	3	4	5	6	7
1. Age (n = 130)	--						
2. K-BIT 2 Full Scale IQ (n = 130)	.02						
3. CIGT Net Score (n = 123)	.24 ^c	-.08					
4. Delay Discounting k (n = 103)	-.28 ^c	-.11	.11				
5. SST Total Score (n = 120)	.48 ^e	.23 ^b	.01	-.28 ^c			
6. BCST Total Correct Responses (n = 116)	.35 ^d	.22 ^b	.14	-.31 ^c	.35 ^d		
7. BCST Perseverative Errors (n = 116)	.09	-.07	.11	.01	.20 ^b	.10	--

Note. K-BIT 2 = Kaufman Brief Intelligence Tests-2; 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

Group Differences Across “Hot” and “Cool” Executive Function Tasks

	Mean (SD) for Each Group			F	p
	ADHD-ODD	ADHD+ODD	Control		
“Hot” Executive Functions					
Univariate ANCOVA Tests					
DDT <i>k</i>	.95(2.10)	.62(1.96)	.41(1.15)	1.50	.23
CIGT Net Scores	.97(19.52)	−2.39(22.31)	−7.07(15.43)	2.15	.12
“Cool” Executive Functions					
Overall MANCOVA Test					
Wilks $\lambda = .77$				4.57	.0002
Univariate ANCOVA Tests					
SST Total Scores	5.80(1.76)	6.07(2.42)	7.13(1.70)	6.56	.002
BCST Total Correct Responses	36.27(10.45)	33.74(12.23)	43.13(9.59)	7.55	.0009
BCST Perseverative Errors	11.24(6.78)	8.82(6.42)	9.90(4.29)	1.36	.26

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.