Executive Functions in Children with ADHD or Internalizing Symptoms

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Abstract

Children with disorders such as attention-deficit/hyperactivity disorder (ADHD), anxiety, or depression often struggle academically and face poorer life outcomes. Impaired cognition in children with disorders could be the result of deficits in executive functions (EFs). EFs are attentional processes that coordinate and control other cognitive processes, and support goal-directed behaviors. Large behavioral studies have reported four main factors of EF: inhibitory control, switching, working memory, and updating. Literature is mixed as to whether ADHD and internalizing disorders such as anxiety or depression are related to consistent EF difficulties. The strongest evidence is that ADHD may be linked with inhibitory control and working memory deficits, while anxiety and depression may be linked with switching and working memory deficits. This study examined the relationships between three tests of EF ability and symptoms of inattention, hyperactivity/impulsivity, and internalizing problems in children, using continuous measures of symptom burdens and EF abilities. Response times on the switching task related most strongly to disorder symptom burdens, with faster responses correlated with lower parent-rated ADHD symptom burdens and higher self-rated internalizing symptom burdens. However, these scores were not significantly different based on presence or absence of a diagnosis. Our results indicate that continuous measures of symptom burdens across a large sample of children were more sensitive than diagnostic information in identifying relationships between EF abilities and symptoms of ADHD and internalizing disorders. Results are discussed in the context of diagnosis, EF variability, and child-parent scoring consistency.

Children with psychopathology including anxiety, depression, or attention-deficit/hyperactivity disorder (ADHD) often have poorer academic achievement in school (Cuffe et al., 2015; Mayes & Calhoun, 2007; Owens et al., 2012). Some evidence suggests that deficits in executive functions (EFs) may mediate the link between these childhood disorders and academic achievement (Biederman et al., 2004; Owens et al., 2012). Executive functions (EFs) are a set of supervisory neurocognitive processes that allow us to solve problems and work toward goals (Blair & Diamond, 2008; Engelhardt et al., 2015). This study investigated the relationship between EF ability and symptoms of ADHD and internalizing disorders in children. We predicted that symptoms of inattention and hyperactivity/impulsivity would be associated with deficits in inhibitory control and working memory, and internalizing symptoms would be associated with deficits in switching and working memory. We also predicted that diagnosis status would relate less to EF abilities than continuous measures of symptom burdens.

Executive functions

Historically, a wide range of skills have been referred to as EFs, such as tolerating negative emotions, planning, reflective learning, choosing and implementing strategies to solve problems, and stopping and switching strategies when necessary (Logan, 1985; reviewed in Zelazo, Blair & Willoughby, 2016). As studies have collected more diverse data and run more sophisticated models using a large battery of control-demanding tasks, EFs cluster into four main factors: inhibitory control, switching, working memory, and updating (Blair & Diamond, 2008; Engelhardt et al. 2015; Engelhardt et al., 2016). Inhibitory control is the ability to direct attention away from a salient stimulus or to stop oneself from a prepotent response to a stimulus (Logan, 1994; Miyake et al., 2000). Switching, also called cognitive flexibility or set-shifting, involves juggling multiple tasks and switching between different goals or perspectives as needed

(Monsell, 1996; Miyake et al., 2000). Working memory requires maintaining information in one's mind, while updating is the ability to manipulate that working memory information. Working memory and updating are thus closely-related skills required to complete many multi-step processes, such as performing mental arithmetic, or holding phone numbers in mind (Lehto, 1996; Miyake et al., 2000).

EFs in children are associated with a host of outcomes. Even after controlling for intelligence quotient (IQ) and socioeconomic status (SES), which can influence EFs, young children with greater EFs are more likely to learn quickly (Benson et al., 2013; Zaitchik, Iqbal & Carey, 2014), do well in school (Bull & Scerif 2001; Duckworth & Seligman, 2005; Clark, Pritchard, & Woodward 2010), graduate high school and college (Vitaro et al., 2005; McClelland et al., 2013), be physically healthier, and have a higher SES as adults (Moffit et al., 2011). The interaction between experiences and EFs is also bidirectional; not only do experiences influence EFs, but EF abilities also influence experience. For example, extreme poverty, poor education, and inadequate caregiving are risk factors for both poor EFs and poor academic performance (Masten et al., 2012; Bernier et al., 2012). However, children living in poverty who possess strong EF skills do not show poor academic performance (Masten et al., 2012). Thus, EF abilities can potentially act as a buffer to life adversity.

EFs are also malleable; they appear to be influenced by life experience as well as by one's current state. Negative emotions, disengagement, and excessive stress are linked with impaired EFs, while positive emotions and moderate stress are linked with improved EFs (Gerstorf et al., 2008; Zelazo, Blair & Willoughby, 2016). Temperament and personality traits including conscientiousness, openness, and grit are linked with EFs as well (Rothbart, 2011; Shiner & DeYoung, 2013; Duckworth & Seligman, 2005). Circadian rhythms, the daily cycle of arousal that regulates sleep and other physiological processes, are also linked with EF task performance. Younger children, whose arousal tends to peak earlier in the day, perform better on EF tasks in the morning. During puberty, arousal peaks later in the day, and older children tend to perform better on EF tasks in the afternoon (Hahn et al., 2012).

Impact of childhood disorders on EF abilities

ADHD and EF. ADHD is a developmental diagnosis that reflects difficulty controlling impulses, restlessness and/or problems focusing relative to peers. ADHD is an externalizing disorder, which means that negative behaviors associated with the disorder are directed outward toward others. For example, hyperactivity in class can be a distraction to others and hinder teachers' lesson plans. The lifetime prevalence of ADHD in children in the US is 11 percent (Visser et al., 2014).

While ADHD presents symptoms consistent with a disorder of control, research on the effects of ADHD on EFs has yielded mixed results. Most research supports the view that ADHD is associated with impairment in certain EFs, but not all EF processes (Barkley & Murphy, 2010; Pennington & Ozonoff, 1996; Alderson et al., 2015). Poor inhibitory control has most often been associated with ADHD, though working memory is also implicated. However, many studies have found contrary results, with some finding deficits across all the EFs and others finding no deficits in EFs in children with ADHD (reviewed by Weyandt et al., 2014). The presence of impaired EFs is not necessary for an ADHD diagnosis (Weyandt et al., 2014).

Anxiety and Depression and EF. Internalizing disorders are characterized by inward distress and negative behaviors toward oneself. Depressive disorders, anxiety disorders, trauma-related disorders, dissociative disorders, and eating disorders fall into this category (American Psychiatric Association, 2013). About 8 percent of children ages 13-18 report being severely impaired by at least one anxiety disorder, and 11 percent report being severely impaired by a mood disorder such as depression or bipolar disorder (Merikangas, 2009).

Anxiety and depression show a similar mixed relation to EF abilities as ADHD (Toren et al., 2000; Channon, 1996; Han et al., 2016). Symptoms of anxiety and depression may be most related to impaired task switching in children (Toren et al., 2000; Hruska et al., 2017; Emerson, Mollet and Harrison, 2005). Anxiety and depression have also been linked to working memory deficits (Favre et al., 2009). However, some research shows no impairment in EFs in children with internalizing disorders (Peyre et al., 2015), and some even indicates that anxiety could be linked to greater inhibitory control, perhaps because anxiety is associated with overactive inhibition (Yurtbasi et al., 2015). Thus, there is a need for larger studies of disorder burden and EF abilities across both internalizing and externalizing (e.g. ADHD) diagnoses.

Variability in Diagnosis of Childhood Psychopathology

Previous research on EF impairments and childhood psychopathology often has grouped children by the presence or absence of a diagnosis of interest, and then compared the mean EF abilities of the two groups. However, there are reasons to propose that using diagnosis as the group criteria provides a skewed sample of participants. Factors such as socioeconomic status and health insurance affect whether a child is diagnosed with a disorder. Children in families with higher socioeconomic status have greater access to mental health care (Hamed, Kauer, & Stevens, 2015). Parental beliefs about child behavior and cultural beliefs setting also affect whether a child is diagnosed. Children’s educational settings also influence whether they are diagnosed; for example, in many cases teachers refer children to be assessed for ADHD. Educational policies and individual teachers therefore may influence whether a child is diagnosed (Hamed, Kauer, & Stevens, 2015). Additionally, the prevalence of childhood disorders sometimes varies by state. For example, lifetime prevalence of ADHD in the US ranges from 5.6 percent in Nevada to 18.7 percent in Kentucky (Visser et al., 2014). States with the highest prevalence of ADHD are located mostly in the Midwest and South, while states with the lowest prevalence are located mostly in the West and Northeast. Notably, the medication-based treatment of those with ADHD is highest along the East Coast and in the Midwest and Southwest (Visser et al., 2014). These geographical, socioeconomic, familial, cultural, and educational factors all affect whether or not a child is diagnosed with a disorder, beyond the child's symptoms of a disorder.

Additionally, diagnostic criteria of disorders continue to evolve. For example, the behavioral symptoms of attention problems, hyperactivity, and impulsivity have been described for over 200 years, but the formal diagnosis of ADHD has a short history (Antshel, Hier & Barkley, 2014). In the past 50 years, various editions of the DSM have organized the same symptoms differently, as "hyperkinetic syndrome," which emphasized overactivity (American Psychiatric Association, 1968), "attention deficit disorder with hyperactivity" and "attention deficit disorder without hyperactivity" (American Psychiatric Association, 1980), and the current DSM-V description that ADHD is one diagnosis with three subtypes: predominantly inattentive, predominantly hyperactive/impulsive, and combined presentation (DSM-5; American Psychiatric Association, 2013). As the diagnosis evolves, ADHD is increasingly recognized and diagnosed. The percentage of children diagnosed with ADHD rose 42 percent between 2003 and 2011 (Visser et al., 2014). Thus, more recent studies include more children as having a diagnosis, though their symptoms may or may not have been diagnosed as ADHD in the past.

Finally, ADHD, anxiety, and depression are broad diagnoses that could reflect different symptoms in different children. For example, hot EFs, those used in emotionally-salient situations, and cool EFs, those used in emotionally-neutral situations, may underlie different subtypes of ADHD. Impaired cool EFs may cause more attention and academic problems, while impaired hot EFs may cause more hyperactivity, impulsivity, and social problems (Castellanos et al., 2006). Thus, different underlying brain processes may cause different symptoms of ADHD and impairments in EFs.

One solution to these problems would be to use a consistent symptom burden measure across a large, community-based sample of children. Symptom burden refers to the prevalence, frequency, and severity of an individual's symptoms (Gapstur, 2007). Symptom burden is measured as a continuous variable and therefore provides more nuanced information about children's symptoms than does the presence or absence of a diagnosis. In line with the National Institute of Mental Health Research Domain Criteria (RDoC) initiative, this study evaluated the relationship between children's EFs and ADHD and internalizing symptom burdens in order to clarify how symptom burdens related to EF abilities (Insel, 2014). The goal of the RDoC project is to improve research by focusing on objective, biologically valid measures of mental illness instead of traditional DSM diagnoses that group heterogeneous syndromes together. The RDoC recommends the use of continuous measures of symptoms as one way to improve research. By following this recommendation, this study attempts to provide a clearer picture of the relationship between EFs and inattention, hyperactivity/impulsivity, and internalizing symptoms.

Assessment of Executive Functions

Deficits in EFs are associated with several disorders, yet EFs are challenging to assess. A variety of measures are used to assess EFs, including behavioral tasks and questionnaires. However, not all measures accurately tap into the same set of processes. Behavioral tasks provide a standardized, objective measure of EFs but are criticized for lacking ecological validity. For example, the Stroop test is a classic measure of inhibitory control in which the participant sees the name of a color (e.g., "green") written in a different color (e.g., red) and must say the color the word is written in (red) while suppressing the automatic response to read the word ("green") (Stroop, 1935). However, emotionally neutral laboratory tasks such as the Stroop task may not reflect true situations that require EFs (Barkley & Murphy, 2010; Burgess et al., 1998). Single behavioral tasks also cannot isolate specific EF factors for assessment. The Stroop task, for example, measures not only inhibitory control, but also cognitive flexibility, verbal ability, and processing speed. Using a variety of tasks to measure EFs can alleviate this problem. For example, a computerized inhibition task in which participants press a key rather than speak could clarify whether a score on a Stroop task was influenced more by verbal ability than by inhibition (Miyake, Emerson, & Freidman, 2000). Similarly, collecting other measures of processing speed could allow separation of inhibition from speed-related effects. While behavioral measures of EFs have limitations, questionnaires that were created to address these limitations have proven to be problematic in different ways.

Questionnaires are less influenced by in-the-moment factors such as a child's mood and arousal than behavioral tasks. However, questionnaires do not correlate well with EFs as measured in behavioral tasks, and they can be subject to rater bias (Blijd-Hoogewys, Bezemer, & van Geert, 2014). For example, questionnaire scores may be influenced by other variables in a child's behavior, such as likeability, more than a child's executive functioning (Barkley & Hoffman, 2007). Further, EF questionnaires are rarely completed by the child, and thus relate more directly to observed EF ability than EF ability per se. Thus, questionnaires may represent a broad picture of a child's behavior in various settings more than they represent the factors of switching, inhibitory control, and working memory/updating. Since this study examined the relationship between symptom burdens and the EFs, precise measures of the different factors were required. This study therefore used performance on three EF behavioral tasks rather than questionnaires to measure EFs in participants.

Conclusion

The current study aims to create a better understanding of how attention, hyperactivity/impulsivity, and internalizing symptoms are associated with children's EFs. Switching, inhibitory control, and working memory/updating are the core EF factors that allow us to choose, execute, monitor, and stop or switch strategies to achieve a goal (Engelhardt et al., 2015; Logan, 1985). EFs are essential to our abilities to plan, learn, reflect, and control our emotions, thoughts, and behaviors. EFs have been linked to numerous academic, social, economic, and health outcomes (reviewed by Zelazo, Blair & Willoughby, 2016).

Studies of EFs in children with ADHD show mixed results, as do studies of EFs in children with anxiety or depression. However, the findings with the most support at this time are that children diagnosed with ADHD often have impaired inhibitory control and working memory, while children with anxiety and depression often have deficits in switching and working memory (Wilcutt et al., 2005; Ozonoff & Jensen, 1999; Emerson, Mollet and Harrison, 2005; Favre et al., 2009). In order to clarify the mixed conclusions of past research on the relationships between EFs and internalizing, inattention, and hyperactivity/impulsivity symptoms, this study used symptom burdens as continuous variables. The use of continuous measures instead of diagnostic categories allowed for a more nuanced examination of the relation between EFs and symptom burdens for developmental disorders.

Materials and Methods

Study Design Overview

This study analyzed the relationship between behavioral measures of EFs and symptoms of inattention, hyperactivity/impulsivity, and internalizing (i.e., anxiety, depression) symptoms in children. Children with and without a diagnosis of ADHD, anxiety, and/or depression were included to capture a wide range of symptom burdens. Inattention, hyperactivity/impulsivity, and internalizing symptom burdens were assessed with widely-used, standardized parent and self-reports of children's behaviors. Parent- and self-reported inattention and hyperactivity/impulsivity symptom burdens were measured by the Conners 3 Parent Short and the Conners 3 Self-Report Short (Conners, 2008). Self-reported internalizing symptom burden was measured through the Multidimensional Anxiety Scale for Children (MASC; March et al., 1997), and parent-reported internalizing symptom burden was measured through the Child Behavior Checklist (CBCL; Achenbach & Rescorla, 2001). Three computer tasks were administered to assess three core EF factors: inhibition, switching, and working memory/updating. Children completed the Stop-Signal Task (SST) to assess motor inhibition (similar to Logan, Schachar, & Tannock, 1997; Verbruggen, Logan, & Stevens, 2008), the CogFlex task to assess switching (Baym et al., 2008; Church et al., 2017; Bauer et al., 2017), and the N-Back task to assess working memory/updating (Jaeggi et al., 2010).

We hypothesized that inattention and hyperactivity problems would be linked to inhibitory control and working memory deficits, while internalizing symptoms would be linked to switching and working memory deficits, consistent with the extant literature. We predicted that diagnosis status would relate less to EF abilities than using continuous measures of symptom burdens.

Participants

This study analyzed data from an ongoing study of executive function development in Dr. Jessica Church-Lang's Developmental Cognitive Neuroscience Lab at the University of Texas at Austin. Participants were 120 children (47 girls) ages 8-18 years from 76 families. Fliers with study information were placed in the Austin community, in schools and at psychologists' offices to recruit children both with and without a diagnosis of ADHD. Exclusion criteria eliminated 26 other children from this study. Children with a diagnosis of autism were excluded (n = 6), as autism has also been linked to deficits in EFs that could skew the data (Blijd-Hoogewys, Bezemer & van Geert, 2014; Ozonoff & Jensen, 1999). Additionally, children with any incomplete symptom questionnaires or computer tasks were excluded (n = 3). Children with extremely outlying scores on symptom burden questionnaires were excluded (n = 3). Finally, as explained below, children with scores indicating they did not complete all computer tasks in the intended manner were excluded (n = 14). Of the 120 included, 54 children had an existing diagnosis of ADHD, and 13 children had an existing diagnosis of an internalizing disorder (anxiety and/or depression). Eight children had both an ADHD diagnosis and an internalizing diagnosis. Children without a diagnosis of ADHD or an internalizing disorder were unmedicated. Twenty-two diagnosed children were medicated: 18 children with an ADHD diagnosis, and 8 with an internalizing disorder (4 with both diagnoses were medicated). Children were compensated 50 dollars and parents were compensated 20 dollars for their time.

Materials and Measures

Attention/Hyperactivity Measures. The Conners 3 Parent Short questionnaire assesses ADHD symptoms and symptoms of commonly comorbid disorders (e.g., Oppositional Defiant Disorder and Conduct Disorder) in children ages 6-18 years (Conners, 2008). It consists of 43 questions that are rated on a four-point Likert scale and two open-ended questions, and it is completed by the child's primary caregiver. The Conners 3 Parent Short measures key areas of functioning or symptoms in six content subscales, of which the Inattention and Hyperactivity/Impulsivity subscales were used.

The Conners 3 Self-Report Short contains 41 questions rated on a four-point Likert scale and two open-ended questions, and it is completed by children ages 8-18 years. The Conners 3 Self-Report Short measures key areas of functioning or symptoms in five content subscales, of which the Inattention and Hyperactivity/Impulsivity subscales were used.

The Conners 3 shows test-retest reliability, with Cronbach's alpha values ranging from .71 to .98 (Conners, 2015). The Conners 3 also shows internal consistency with Cronbach's alpha values ranging from .77 to .97. The measure also demonstrates convergent and divergent validity when compared to the Behavior Assessment System for Children, Second Edition, and the Achenbach System of Empirically Based Assessment, both of which are established measures of hyperactivity and attention problems. Conners 3 correlations with these measures ranged from .41 to .96. Finally, discriminant function analyses showed good discriminative validity (77.6% for the parent report and 72.9% for the self report) in differentiating children and adolescents with and without ADHD.

Internalizing Measures. The CBCL for Ages 6-18 is a standardized measure of internalizing and externalizing problems that is completed by the child's primary caretaker (Achenbach & Rescorla, 2001). The CBCL is divided into two components: The first measures a child's competency in various contexts and the second measures a child's internalizing and externalizing problems. This second component assesses internalizing and externalizing problems through 113 questions on a three-point Likert scale and generates eight scales measuring various internalizing and externalizing problems. From these eight scales, the CBCL generates two broad band scales of internalizing and externalizing syndromes. This study used the broad band Internalizing scale, which is computed from the sum of the Anxious/Depressed scale (13 questions), Withdrawn-Depressed scale (8 questions), and Somatic Complaints scale (11 questions). The CBCL Internalizing scale shows high test-retest reliability (Cronbach's α = .90) and cross-informant reliability between mother and father ratings ($r = .72$). All CBCL behavioral problem questions show content validity in discriminating between children with and without behavioral disorders significantly ($p < .01$; Achenbach & Rescorla, 2001).

The MASC is a child self-report of anxiety symptoms for ages 8-19 years (March et al., 1997). It consists of 39 questions rated on a four-point Likert scale. The MASC shows strong test-retest reliability ($r = .93$) and internal consistency (Cronbach's α = .90). The MASC shows discriminative validity in differentiating children with anxiety disorders and is correlated with the Revised Children's Manifest Anxiety Scale ($r = .63$) (March et al., 1997). The MASC Total is the sum of scores on the Physical Symptoms scale (12 questions), Harm Avoidance scale (9 questions), Social Anxiety scale (9 questions), and Separation/Panic scale (9 questions).

Inhibitory Control Measure. The stop-signal task (SST) was developed to measure inhibitory response control (Logan, Schachar, & Tannock, 1997; Verbruggen, Logan, & Stevens, 2008). Participants saw 127 trials comprising "go" and "stop" trials. In "go" trials (n = 95), participants saw an arrow on the screen (for 1000ms) and were asked to quickly press a key indicating whether the arrow was pointing left or right. In "stop" trials (n = 32), the "stop signal," a red X, appeared on top of the arrow after the arrow was presented but before the participant pressed a key, indicating that the participant should not press any key (see Figure 1). This task pushed the participant's proportion of accurate stop-signal trials to 50 percent by staircasing the stop signal +/-50ms (beginning at 250ms) so that it appeared faster when the participant failed to stop previously, and later when the participant successfully stopped previously. The motor response is more difficult to inhibit when the stop signal comes later. The participant's stop signal reaction time (SSRT) is calculated as a measure of response time reflecting how quickly a participant can inhibit a motor response (Congdon et al., 2012). The SSRT is the mean response time on "go" trials minus the mean stop-signal delay, or the delay between the arrow and the stop signal appearing. A child's accuracy score is the proportion of correct "go" trials. Participants with "go" accuracy under 60 percent or "stop" accuracy over 75 percent were excluded from analysis. Since the task was designed to push "stop" accuracy to 50 percent, participants with scores much higher than this may have completed the task slowly to increase accuracy (Englehardt et al., 2016). Participants with low "go" accuracy may not have understood the task or may have used a strategy of pressing keys as quickly as possible without attending to accuracy in order to lower response time.

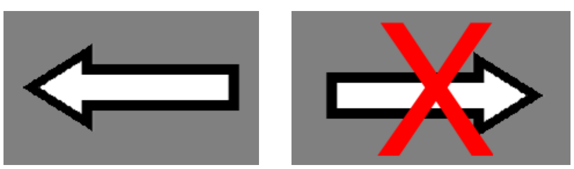

Figure 1. Stop Signal Task "Go" and "Stop" Trials. "Go" trials presented a left or right arrow, while "stop" trials presented a left or right arrow followed by a variably timed red X, indicating the participant should not press any key.

Switching Measure. In the CogFlex game, a measure of cued task switching, participants were cued to attend to different aspects of a target stimulus, prior to the target's arrival on screen. First, participants saw a rule cue indicating to them whether to attend to the shape or color of the upcoming target (0-1500ms), and two possible response choices, each reflecting one of two shapes and colors. There was then a delay period of 500ms. The target then appeared below these two response choices (for 2000ms) (see Figure 2). Each trial lasted for 4000 total milliseconds. For each trial, participants pressed a key to indicate which response choice matched the target figure on the cued rule (Baym et al., 2008; Bauer et al., 2017; Church et al., 2017). The rule sometimes switched and sometimes did not switch between trials. Participants responded to one block of 46 trials in this task. Accuracy was measured as the proportion of correct trials, and response time was measured as the average response time across correct trials. Since 50 percent is the score a participant would receive by pressing keys at random, participants with accuracy under 60 percent were excluded from analysis to ensure that participants understood the task. Accuracy and response time were used as dependent variables.

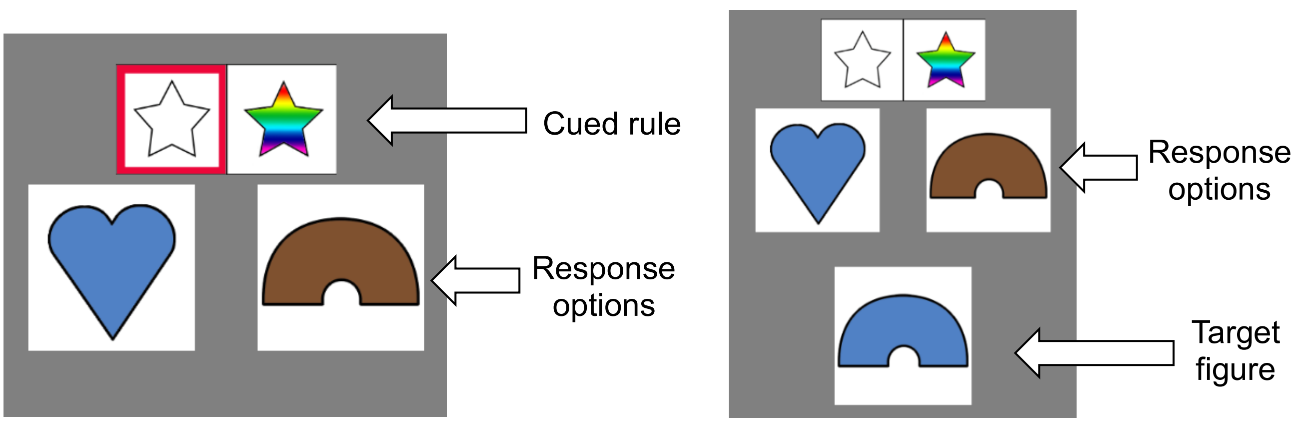

Figure 2. CogFlex Task Sequence. A cued shape (outlined star) or color (rainbow star) rule was indicated by a red box highlighting the relevant rule for a given trial. The red box was presented for 1500ms, followed by a 500ms delay period before the presentation of the target stimulus. Participants then viewed a target figure and matched it to the response options given based on the cued rule. In this example, the rule is “shape”, and the correct answer would be the right button (the brown arc response). The relative size of the stimuli have been altered for visibility in this figure; they were smaller and did not change size during the cue or target period.

Working Memory/Updating Measure. The N-back task is a measure of working memory/updating. Participants viewed continuous sequences of single shapes and identified when a shape matched either the one shown immediately before (1-back), or the one shown two shapes earlier (2-back; see Figure 3; Jaeggi et al., 2010). Participants viewed 128 shapes in total across two blocks of 1-back trials alternating with two blocks of 2-back trials. There were 7 correct "hits" per task block out of 32 shapes. A child's accuracy score reflected the difference between the number of correct indications of a match and the number of false identifications of a match, calculated separately for 1-back and 2-back blocks of trials. Response time was measured as the mean response time on correct indications of a match. Participants with a negative accuracy score (more false identifications of a match than correct matches) in 1-back trials were excluded from analysis, as this score indicated the participant may not have understood or attempted the task. Accuracy and response time scores were used as dependent variables.

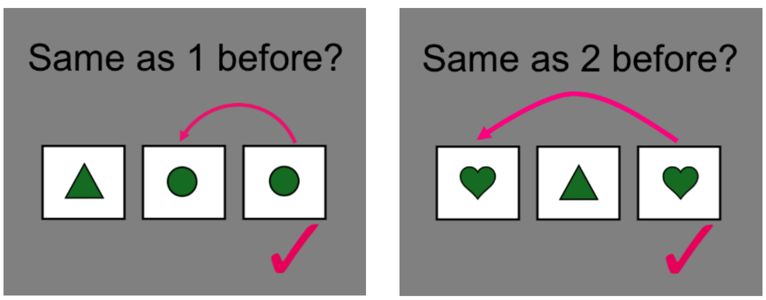

Figure 3. N-Back Task Instructions. Participants responded to a series of shapes presented one at a time, indicating by button press when a figure matched the one shown just before (1-back blocks of trials) or shown two before (2-back blocks of trials).

Procedures

Parents gave informed consent for children to participate in the study, and children gave assent to participate. Children completed the computerized EF tasks and self-report questionnaires in a separate testing room with a researcher, while their parents completed the symptom burden questionnaires and additional surveys in the general lab space. Children first completed the SST, followed by the N-back task, followed by the CogFlex task. After completing the behavioral tasks, children completed the self-report questionnaires measuring inattention and hyperactivity problems and internalizing symptoms. The behavioral visits from which this subset of data were analyzed occurred between Nov. 5, 2016, and Nov. 18, 2017. The visits lasted approximately 4 hours and included additional measures not analyzed in this study. See Appendix A for a full list of measures completed in the visit.

Statistical Analyses

For each participant, the following data were analyzed: age, gender, race, family income, six symptom burden scores, and six executive function task scores. The six symptom burden scores consisted of three scores from parent reports and three scores from child self-reports, measuring symptoms of inattention, hyperactivity/impulsivity, and internalizing problems. Internalizing symptom scores were drawn from the raw CBCL Internalizing scale score (parent report), and the raw MASC Total score (child self-report). The inattention and hyperactivity/impulsivity symptom scores were drawn from the same-named components of the raw Conners 3 Parent Short and the raw Conners 3 Self-Report Short. Executive function scores were composed of response times and accuracies for each of the three EF computer tasks described above. Medication usage was not analyzed in this study.

Parents completed the CBCL and the Conners 3 assessments on REDCap, (Research Electronic Data Capture) a secure website that manages surveys and databases (https://redcap.prc.utexas.edu; accessed through the Population Research Center at UT; provided courtesy of Vanderbilt University). Children completed the Conners 3 and the MASC on paper, and a lab research assistant entered their answers into REDCap. A second research assistant verified the entry. REDCap automatically generated parent-reported and self-reported Inattention and Hyperactivity/Impulsivity total scores by summing the scores from five questions about attention and six questions about hyperactivity/impulsivity on the Conners 3. The parent-reported Internalizing score was automatically generated in REDCap from the sum of 32 questions on the CBCL, and the child self-reported total MASC score was generated from 39 questions. Data was exported from REDCap into a csv file, and then imported into R for data analysis (R Core Team, 2013).

Pairwise Pearson correlations were analyzed between all variables of interest. Partial correlations controlling for age were then conducted to test which correlations between EF scores and symptom burdens were still significant. The Benjamini & Hochberg Procedure was used to correct p-values for multiple comparisons. Finally, for any EF scores correlated with symptom burdens, Welch's Two Sample t-tests were conducted to examine whether there were significant differences in scores between children with and without the relevant diagnoses.

RESULTS

Participant Demographics

Of 120 children (47 girls, ages 8-18 years) who participated in the study, 54 had a diagnosis of ADHD (20 female, ages 8-18 years), and 13 had a diagnosis of an internalizing disorder (7 female, ages 9-17 years). A Welch's Two Sample t-test showed that there was no significant difference in age between males and females ($p = 0.72$). A Welch's Two Sample t-test confirmed that there was no significant difference in mean age between children with (n = 54) and without (n = 66) an ADHD diagnosis ($p = 0.28$). There were significant differences in age between children with (n = 13) and without (n = 107) a diagnosis of an internalizing disorder (i.e., anxiety and/or depression); children with an internalizing disorder being older ($p = .049$). There were no significant differences in Full Scale Intelligence Quotient between genders ($p = .34$) or between children with and without a diagnosis of ADHD ($p = .37$) or an internalizing disorder ($p = .73$). Eight children had both an ADHD and internalizing diagnosis (5 female). Table 1 shows descriptive measures across the sample.

Table 1

Age (years) across diagnostic groups

Group	**N**	**M *(SD)***	**Min**	**Max**	**Skew**	**Kurtosis**
ADHD diagnosis	54	13.45 (2.49)	8.83	18.62	0.12	-1.06
No ADHD diagnosis	66	12.96 (2.46)	8.18	17.83	0.04	-0.86
Internalizing diagnosis	13	14.56 (2.45)	9.79	17.76	-0.47	-1.12

No internalizing diagnosis	107	13.01 (2.44)	8.18	18.62	0.14	-0.79
Total	120	13.18 (2.48)	8.18	18.62	0.08	-0.88

Note. There were no significant differences in age between children with and without a diagnosis of ADHD ($p = .28$), or between genders ($p = .72$). Children with an internalizing diagnosis were significantly older than those without an internalizing diagnosis ($p = .049$).

As anticipated, children with and without ADHD diagnosis had significantly higher mean scores on the Conners 3 Parent Short Inattention ($p < .001$) and Hyperactivity/Impulsivity ($p < .001$) raw scores and on the Conners 3 Self-Report Short Inattention ($p < .001$) and Hyperactivity/Impulsivity ($p = .019$) raw scores. Children with an ADHD diagnosis had higher mean scores. There was no significant difference in self-report MASC scores between children with and without an internalizing diagnosis ($p = 0.44$), but parent CBCL Internalizing ratings were significantly higher in children with an internalizing diagnosis ($p = .002$).

Correlations between symptom burden and demographic information

Pairwise Pearson correlations between symptom reports, EF task scores, and demographic information were conducted (see Figure 4). Family income was not significantly correlated with any other variable, including EF task scores and symptom burden reports. Age was significantly correlated with faster response times and higher accuracy scores on every EF task ($p < .001$ for all scores except SSRT, $p = 0.037$). Age was significantly correlated with one symptom burden report, hyperactivity/impulsivity. Parents reported significantly higher hyperactivity/impulsivity symptom burdens on the Conners 3 for younger children ($p < .001$).

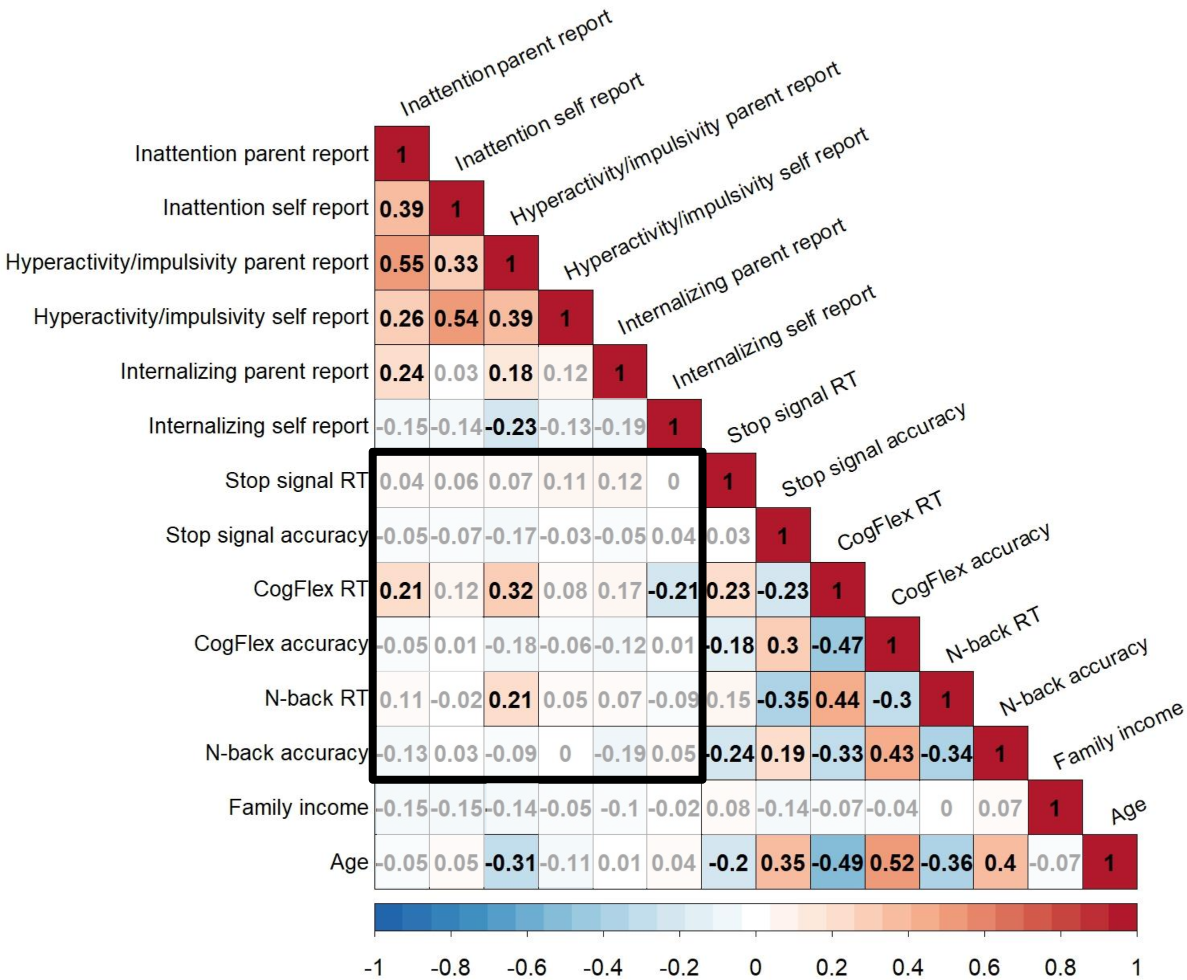

Figure 4. Pairwise Pearson correlations between experimental variables. Correlations that were not significant at the level $p < .05$ are faded. Correlations within the black box show the relationships of interest between symptom burdens and EF scores.

Correlations between Parent-Reported and Self-Reported Symptoms

Parent and child reports of inattention and hyperactivity/impulsivity symptoms were correlated ($r = .72$, $p < .001$; see Figure 5), but parent and child reports of internalizing symptoms were not ($p = .11$; see Figure 6). Parent reports of internalizing symptoms were positively correlated with their reports of hyperactivity/impulsivity symptoms ($r = .18$, $p = .045$) and inattention symptoms ($r = .26$, $p = .004$). However, parent reports of hyperactivity/impulsivity symptoms were negatively correlated with child self-reports of internalizing symptoms (r = -.22, p = .018).

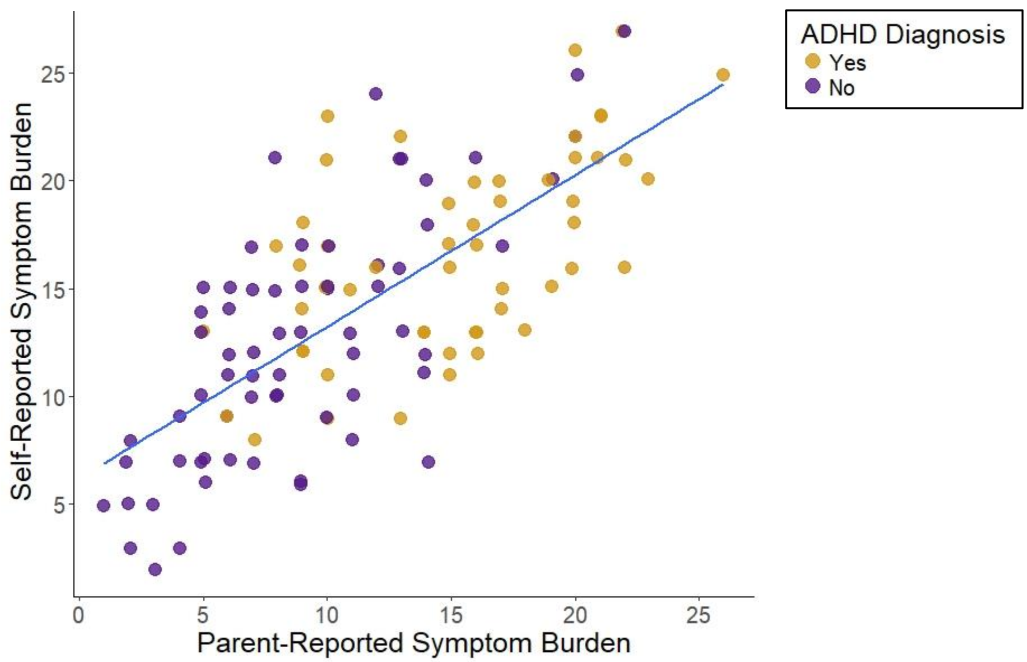

Figure 5. The sums of the Inattention and Hyperactivity/Impulsivity scores for the Conners 3 Parent Short and the Conners 3 Self-Report Short were highly correlated (r = .72, p < .001).

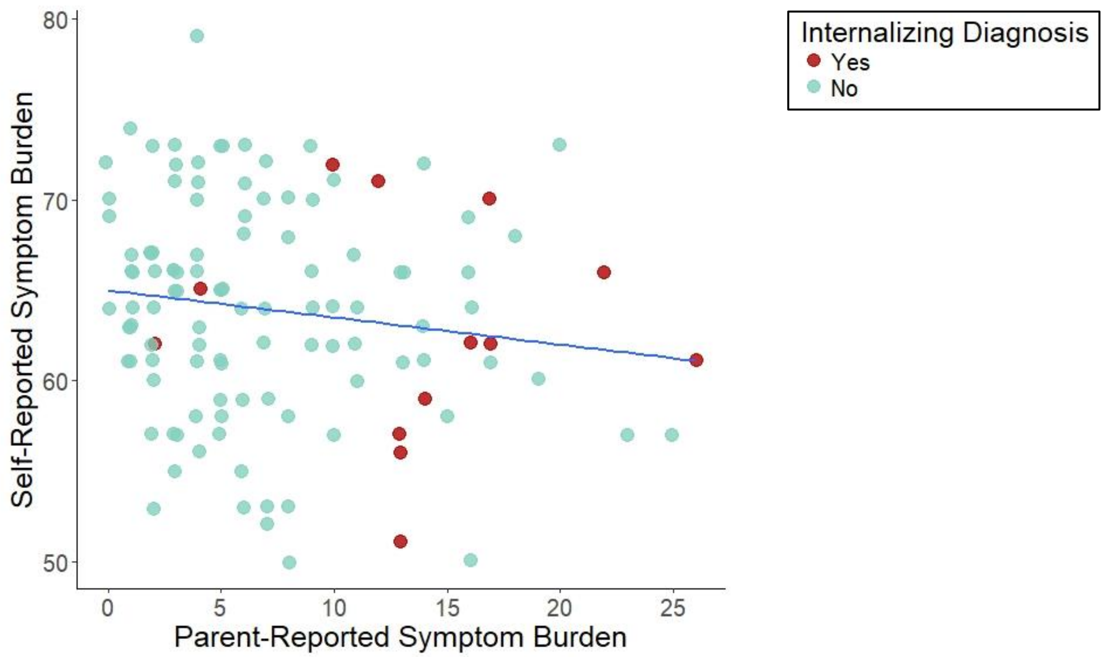

Figure 6. Raw scores on the CBCL Internalizing scale (parent report) and the MASC Total (child self-report) were not correlated (r = -.15, p = .11).

Correlations between EF Task Performance and Symptom Burdens

Faster response times on the EF switching task, CogFlex, correlated with lower parent rating of hyperactivity/impulsivity symptoms ($p < .001$; see Figure 7); higher symptom burden related to slower response times. This result survived multiple comparison correction to decrease the false discovery rate using the Benjamini & Hochberg Procedure ($p = .002$). Weaker but similar results were found for parent-rating of inattention symptoms ($p = .025$). The inattention result was only trending after multiple comparison correction ($p = .08$).

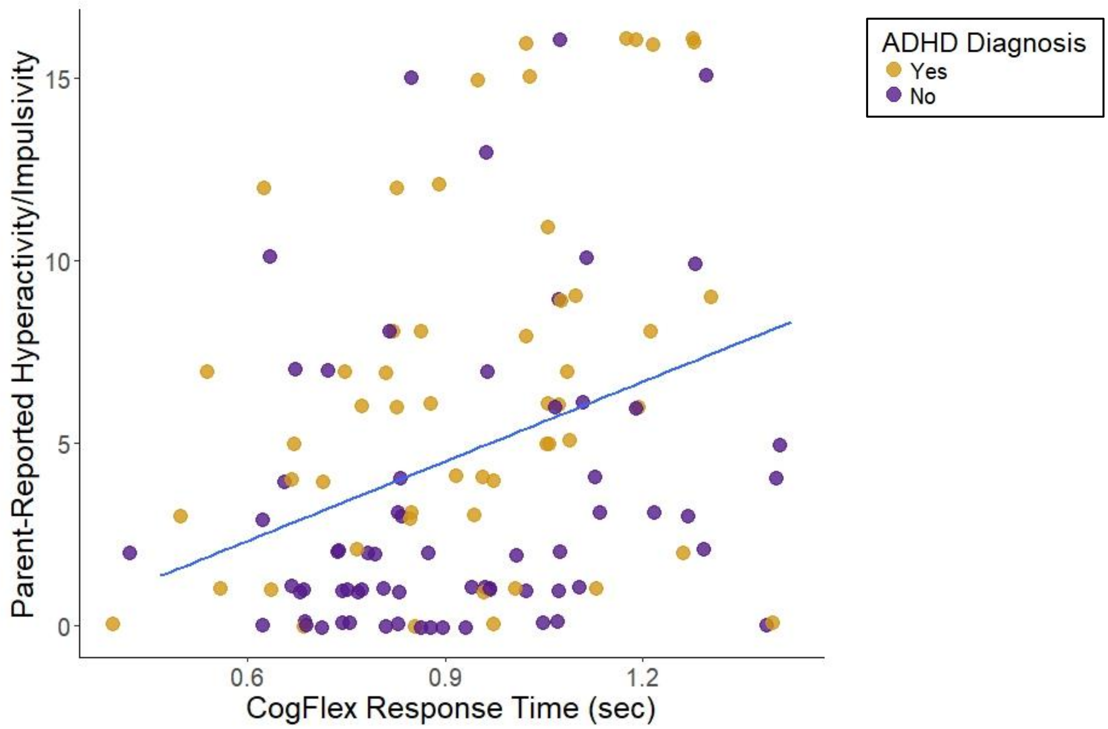

Figure 7. Hyperactivity/impulsivity score on the Conners 3 Parent Short was positively correlated with response times on the EF switching task, such that higher symptom burden was correlated with longer response times on correct trials and thus slower performance of the task ($r = .32$, $p < .001$). This result survived controlling for age ($p = .031$), and multiple comparison correction.

The opposite pattern was found for the child self-ratings of internalizing symptoms; higher ratings of internalizing symptoms correlated with faster CogFlex response times ($p = .0177$; see Figure 8). This result was only trending after multiple comparison correction ($p = .06$).

Before controlling for age, response times on the working memory/updating EF task, the N-back, also correlated with parent-rated hyperactivity/impulsivity symptoms ($p = .0179$), such that higher hyperactivity symptoms related to slower responses, but this result was only trending after corrections for multiple comparisons (p = .06).

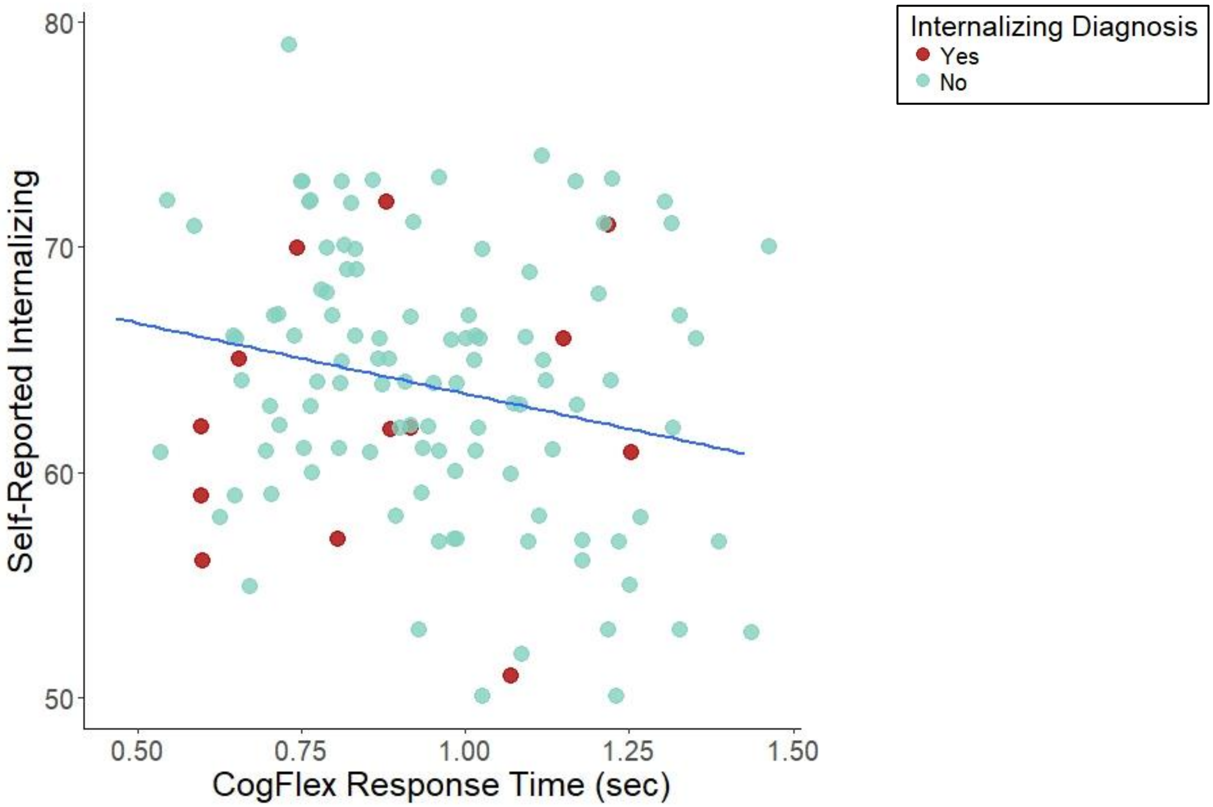

Figure 8. The MASC Total score (from child self-report) was negatively correlated with response times on the EF switching task, such that higher symptom burdens were correlated with lower response times on correct trials and thus faster performance of the task (r = -.21, p = .0177). This result survived controlling for age (p = .017) but did not survive multiple comparison correction (p = .06).

Controlling for Participant Age in Analyses

Because age was significantly correlated with performance on every EF task measure, partial correlations between EF task scores and symptom burdens were conducted, controlling for age. The partial correlation controlling for age between CogFlex response times and parent-rated hyperactivity/impulsivity remained significant (r = .20, p = .031), as was the partial correlation controlling for age between CogFlex response time and parent-rated inattention (r = .21, p = .023). The partial correlation controlling for age between CogFlex response time and self-rated internalizing symptoms also remained significant (r = -.22, p = .017).

The partial correlation between N-back response time and parent-rated hyperactivity/ impulsivity was not significant when controlling for age (p = .20). However, a significant correlation between N-back accuracy and parent-rated internalizing symptoms emerged when controlling for age with a partial correlation (r = -.22, p = .018), such that higher internalizing symptoms related to poorer accuracy.

Diagnosis Status and EF Task Performance

Diagnostic status was not related to any EF task performance. Welch's Two-Sample t-test showed that CogFlex response times did not differ significantly between children with and without an ADHD diagnosis (p = .07) or with and without an internalizing diagnosis (p = .31; see Figure 9). N-back accuracy did not differ between children with and without an internalizing diagnosis (p = .74), and N-back response time did not differ between children with and without an ADHD diagnosis (p = .71).

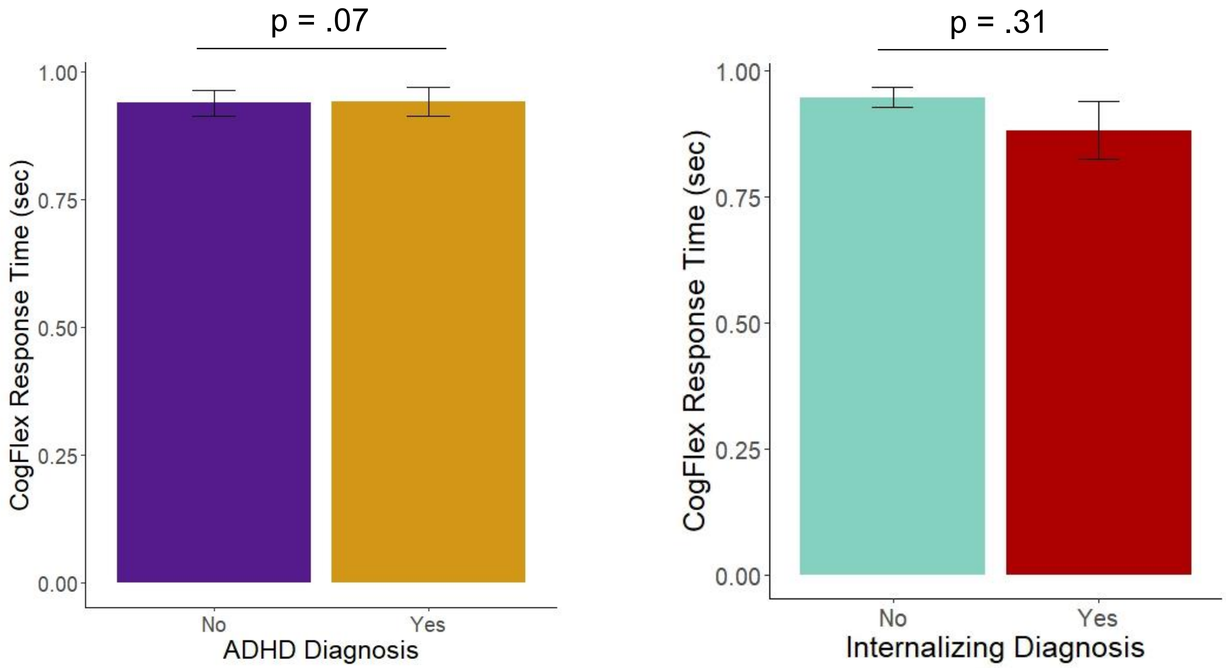

Figure 9. CogFlex response time was not significantly different in children with and without an ADHD diagnosis or internalizing diagnosis.

DISCUSSION

We interrogated the relationships between continuous measures of ADHD or internalizing symptoms and three tests of executive functions. The CogFlex task (an EF switching task) had the strongest correlations with symptom burdens. The N-back task (an EF working memory/updating task) showed similar but weaker correlations with symptom burdens; the SST (an EF task of motor inhibition) did not correlate with symptom burdens. CogFlex response times were correlated with parent-rated levels of hyperactivity/impulsivity and children's self-rated internalizing symptoms. However, CogFlex response times were not related to diagnostic status. Parent and child ratings of ADHD symptoms were highly correlated, but their ratings of internalizing symptoms were not correlated. These results are discussed below.

Symptom burden related to the switching task, rather than the inhibition task

Higher parent-rated hyperactivity/impulsivity and inattention were both correlated with longer CogFlex response times. We did not predict this task would carry the strongest results, because prior research has found ADHD to be associated with poorer inhibitory control (Barkley & Murphy, 2010; Alderson et al., 2015; Ozonoff & Jensen, 1999). We thus expected ADHD symptoms to be negatively correlated with better performance on the SST, rather than the CogFlex task. However, the SST was not correlated with any symptom burden reports. One possibility for this is that the motor inhibition tapped by the SST may not be affected in children with ADHD and/or internalizing disorders, and perhaps other researchers have used other measures of inhibition. Another possibility is that the CogFlex task may recruit aspects of inhibitory control as well as switching ability, since the task requires inhibition of one rule in order to follow the other rule for a given trial. Thus, our results may still be consistent with prior research indicating that inhibitory control is poorer in children with ADHD (Barkley & Murphy, 2010; Alderson et al., 2015; Ozonoff & Jensen, 1999).

Counter to our ADHD symptom burden results, children with higher self-reported internalizing symptom burdens had relatively faster response times on the CogFlex task. This finding is consistent with some prior research indicating that anxiety may be linked to greater inhibitory control (Yurtbasi et al., 2015). However, it is inconsistent with research that has found that children with internalizing disorders have poorer switching ability (Emerson, Mollet and Harrison, 2005). One possible interpretation of our results is that children who are more anxious are more attuned to changing environmental cues such as those in our switching task, and thus were faster at responding.

Since prior research indicates that working memory is poorer in children with ADHD and in children with internalizing disorders, we had predicted performance on the N-back would be negatively correlated with both symptom burdens (Wilcutt et al., 2005, Favre et al., 2009). Before controlling for age, N-back response time was correlated with parent-rated hyperactivity/impulsivity, and after controlling for age N-back accuracy was weakly correlated with parent-rated internalizing symptoms. Our findings were thus consistent with prior research, though the effects were weak.

Diagnostic status not related to EF task performance

Despite the correlations between CogFlex task response times and symptom burdens, response times were not significantly different between children with and without a diagnosis of ADHD or an internalizing disorder. This was consistent with our prediction that continuous measures of symptom burden would be more sensitive than diagnostic categories for detecting relations to executive function ability. Many factors in addition to the severity and frequency of symptoms may affect whether a child is diagnosed with a disorder. Socioeconomic status, health care access and insurance, parental beliefs about child behavior, cultural beliefs, and educational setting may all influence whether a child is diagnosed with ADHD (Hamed, Kauer, & Stevens, 2015). These factors may obscure relationships between disorder symptoms and EF abilities. By studying EF abilities in relation to symptom burdens, we saw relationships that were not observable when looking at diagnostic status alone. Using symptom burdens as continuous variables also allowed a more nuanced approach. ADHD is a broad diagnosis that blurs across those with primary symptoms of inattention and those with primary symptoms of hyperactivity/impulsivity. Examining these symptom burdens separately showed that hyperactivity/impulsivity was more strongly correlated with CogFlex response time than inattention difficulties were.

Parent and child ratings of internalizing symptoms not correlated

Parent and child self-ratings of hyperactivity/impulsivity and inattention were highly correlated, but parent and child self-ratings of internalizing symptoms were not at all correlated. One explanation for this is that the inward nature of internalizing symptoms may make them less apparent to other people, even the child’s primary caregiver. Parent reports of inattention, hyperactivity/impulsivity, and internalizing symptoms were all positively correlated, suggesting that the parent reports may reflect the parent’s tendency to endorse clinical symptoms of any kind in their child. Child self-reports of internalizing symptoms were more correlated with EF task performance than were parent reports, suggesting self-reports of internalizing symptoms may be more useful in EF research. Parent reports of ADHD symptoms were more correlated with EF task performance, suggesting parent reports of these symptoms may be more useful in

EF research. Teacher reports would be interesting comparison points for this research, given the strong relation between EF ability and academic success.

Limitations and future directions

A limitation of this study was that internalizing symptoms were reported by parents and children using different questionnaires with different subscales. ADHD symptoms were reported by both using parent and child versions of the same questionnaire, which could partly explain the greater consistency between these reports and the lack of correlation between internalizing symptom reports. Additionally, children with an internalizing diagnosis were not specifically recruited for this study, while children with an ADHD diagnosis were purposefully oversampled. Future research examining parent and child reports of symptoms should actively recruit children with an internalizing diagnosis as well as children with an ADHD diagnosis and children with neither diagnosis. Internalizing symptoms should be measured using consistent scales for parent and child reports.

Additionally, future research should use multiple tasks to measure each EF factor of interest. The use of multiple tasks and factor analysis to examine the common factor in relation with symptom burdens would help illustrate more clearly which EF factors are related to which symptom burdens. For example, since the SST did not correlate with any symptom burdens, factor analysis of multiple tasks designed to measure inhibitory control would better clarify whether the task was in fact measuring inhibitory control, or whether inhibitory control is related to symptom burden.

Our results highlight the importance of not relying on diagnosis status in evaluating a disorder’s impact on cognitive function. Further research using the methodology of measuring symptoms as continuous variables should continue to yield more nuanced and informative results about the relationship between EF ability and disorder symptom burdens in children.

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Appendix A

Full Procedure

1. Informed consent
2. Rating scales administered by researcher to participant and parent together

Scale	Variable measured	Source
Yale Global Tic Severity Scale	Motor and phonic tics	Leckman et al., 1989
Children's Yale-Brown Obsessive-Compulsive Scale	OCD symptoms	Scahill et al., 1997

3. Parent surveys online
    a. Medication usage, family history, language history, and demographics survey
    b. Child Behavior Checklist (CBCL; Achenbach & Rescorla, 2001)
    c. Conners 3 Parent Short (Conners, 2008)
    d. Social Responsiveness Scale, 2nd edition (parent report of child's behavior; Constantino & Gruber, 2012)
    e. Sleep questionnaire (parent self-report)
4. Behavioral tasks completed by participant

Task	Variable measured	Source
1. Pattern comparison	Processing speed	Salthouse & Babcock, 1991
2. Stop-signal task (SST)	Inhibition	Logan, Schachar, & Tannock, 1997; Verbruggen, Logan & Stevens, 2008
3. Trail making	Switching	Salthouse, 2011
4. N-Back	Working memory/updating	Jaeggi et al., 2010
5. Wechsler Intelligence Scale for Children (WISC)/Wechsler Adult Intelligence Scale (WAIS) symbol search	Processing speed	Wechsler, 2003; Wechsler, 2008
6. CogFlex	Switching	Bauer et al., 2017; Church et al., 2017
7. Animal Stroop task	Inhibition	Wright, Waterman, Prescott, & Murdoch-Eaton, 2003
8. Symmetry span	Working memory	Kane et al., 2004

9. Letter comparison	Processing speed	Salthouse & Babock, 1991
10. Local-global	Switching	Miyake et al., 2000

5. Saliva collection
6. Participant Rating Scales
    a. Pubertal Developmental Scale (PDS; Petersen, Crockett, Richards, & Boxer, 1988)
    b. Conners 3 Self-Report Short (Conners, 2008)
    c. Multidimensional Anxiety Scale for Children 2nd edition (MASC 2; March et al., 1997)
7. Neuropsychological assessments
    a. Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 2011)
        i. Block design
        ii. Vocabulary
        iii. Matrix Reasoning
        iv. Similarities
    b. WISC/WAIS digit span (Wechsler, 2003; Wechsler 2008)
    c. Test of Word Reading Efficiency Second Edition (TOWRE-2; Torgesen, Wagner, & Rashotte, 2012)

Biography

Emily D. Barnes was born in Dallas, Texas and moved to Austin to attend UT as a Psychology and Plan II major. In addition to completing her thesis in Dr. Jessica Church-Lang's lab, Emily's interests in developmental and clinical psychology have led her to work in labs under the mentorship of Dr. Jacqueline Woolley and Dr. Jasper Smits. She has also worked as a research assistant at the Harvard Lab for Developmental Studies under Dr. Susan Carey. Following graduation, she will work as a full-time research assistant at Weill Cornell Medicine under Dr. Rebecca Jones, studying autism in children and anxiety in young adults. Emily is grateful to have spent four years in her favorite city, exploring swimming holes, live music, and taco trucks, and is excited to continue studying psychology in New York.