SOCIAL FUNCTIONING IN CHILDREN WITH ADHD:

AN EXAMINATION OF INHIBITION, SELF-

CONTROL, AND WORKING MEMORY AS

POTENTIAL MEDIATORS

By

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Title of Study: SOCIAL FUNCTIONING IN CHILDREN WITH ADHD: AN EXAMINATION OF INHIBITION, SELF-CONTROL, AND WORKING MEMORY AS POTENTIAL MEDIATORS

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Abstract: The study aims to explore the relative contributions of self-control, behavioral inhibition, and working memory deficits to ADHD-related social problems. Notably, the study adds to the current body of literature due to its use of a Go/No-Go (GNG) inhibition metric, working memory tasks with high central executive demands, and the unique inclusion of self-control. Fifty-eight children with attention-deficit/hyperactivity disorder (ADHD) and 63 typically developing (TD) children participated in the study. Self-control was measured via the task described in Patros et al. (2015), behavioral inhibition was measured using a Go/No-Go (GNG) task, working memory was measured using the Phonological Working Memory (PHWM) task, and parent and teacher social functioning was measured via the Social Problems narrow band scale of the Child Behavior Checklist (CBCL) and Teacher Report Form (TRF). Examination of potential indirect effects with the bootstrapping procedure indicated that the only significant mediator was PHWM for the relationship between group membership (ADHD, TD) and teacher ratings of child social functioning. These findings point to important implications regarding executive functioning difficulties at home compared to school as well as the use of measures that may have multicollinearity with each other (i.e., GNG versus Stop Signal Task). The current findings illuminate the need for more research related to working memory to help target social functioning interventions for children with ADHD.

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CHAPTER I

INTRODUCTION

Attention-deficit/hyperactivity disorder (ADHD) is a neurodevelopmental disorder characterized by symptoms of hyperactivity, impulsivity, and/or deficits of attention (Sagar et al., 2017), and is estimated to be prevalent among 3-7% of school-aged children (Lee et al., 2008; Selikowitz, 2009). Children with ADHD experience a myriad of social problems due to their noncompliant, disruptive, and aggressive behaviors that often result in rejection by peers and ultimately fewer friendships (Erhardt & Hinshaw, 1994; Humphreys et al., 2016). They also tend to experience trouble taking other children's perspectives and often hold a positive illusion of themselves and their actions/competence (i.e., a positive illusory bias; Hoza et al., 2000), which in turn negatively influences their social functioning (Gardner & Gerdes, 2013; Hoza et al., 2004). Moreover, aggression and hostility can be seen in children with ADHD, and they commonly incorrectly assume aggressive intentions from others in situations that are neutral (i.e., a hostile attribution bias; Rosen et al., 2014). To that end, children with ADHD regularly experience trouble forming and maintaining age-appropriate relationships (Cleminshaw et al., 2020; Morris et al., 2021), are often rejected by their peers (Mrug et al., 2001; Hoza, 2007), tend to have fewer friends overall (Bagwell et al., 2001; Hoza et al., 2005), and are less likely to be chosen by popular children (Hoza et al., 2005). Indeed, a meta-analytic review of 109 studies of social functioning in children with or at risk for ADHD found evidence of significant moderate-magnitude deficits in ADHD-related peer-functioning (i.e., friendships, popularity, and peerrejection/likeability), small but significant-magnitude deficits in ADHD-related social skills (i.e., prosocial behavior and social skills performance), and small but significant-magnitude deficits in ADHD-related social information processing (i.e., positive illusory bias and hostile attribution bias; Ros and Graziano, 2018). Children with ADHD also exhibit significant impairments in a broad range of neurocognitive/executive functions (e.g., working memory, behavioral inhibition, and self-control; Logan & Cowan, 1984; Barkley, 1997; Baddeley, 2007; Rapport et al., 2008; Sonuga-Barke et al., 2010), and not surprisingly, a growing body of literature has begun to examine ADHD-related executive function deficits as predictors or mediators of social functioning impairments that are characteristic of the disorder. Examinations of aggregate metrics of executive functioning have reported relatively equivocal findings. For example, Biederman et al. (2006) reported that executive functioning impairments in youth with ADHD significantly predicted social functioning deficits, while Motamedi et al. (2015) suggested that impaired executive functions mediated the relationship between ADHD-related symptoms and social functioning. In contrast, Diamantopoulou et al., (2007) and Tamm et al. (2021) found that executive function impairments are not predictive of ADHD-related social functioning deficits, and Huang-Pollock et al.'s (2009) mediation study did not report evidence of an indirect effect of ADHD-related symptoms on social functioning through executive functions. A number of factors likely contribute to the heterogeneous findings across studies, such as between-study variability in diagnostic/grouping methods (e.g., parent and teacher ratings versus a referral source and structured interview), the use of a clinical control group versus a typically developing control group or the lack of a control group, and the specific metric of social functioning. Moreover, the aggregation of multiple executive functions into a single metric is expected to contribute to between-study heterogeneity, given the range of possible executive functions and corresponding indices that might be included in aggregate measures. To that end, more focused examinations of specific executive functions and ADHD-related social impairments have also been equivocal, with one study finding support for a relationship between working memory and social impairments (Kofler et al., 2011) and another reporting a null effect (Fried et al., 2016). Consideration of the studies' methodologies may provide insight about potential causes for the differences in findings (i.e., grouping methodology, working memory metric).

Only a handful of studies have concurrently examined multiple executive functions to parse the unique contributions, in the face of multicollinearity and construct overlap, of each toward social functioning in children and youth with ADHD (Kofler et al., 2018; Miller & Hinshaw, 2010; Rinsky & Hinshaw, 2011). For example, Kofler et al. (2018) used a Bayesian framework to examine working memory, processing speed, and behavioral inhibition as predictors of ADHD-related social functioning impairments, and found that working memory and core ADHD symptoms (inattention, hyperactivity, and impulsivity), but not behavioral inhibition, served as significant predictors of social problems and social skills acquisition. Kofler and colleagues' (2018) findings are notable as they contrast findings from previous studies that suggest inhibition deficits, rather than specific working memory deficits, significantly predict adolescent social functioning independent of group status (Miller & Hinshaw, 2010; Rinsky & Hinshaw, 2011), and highlight the role of methodological variability in estimating the complex relationship between these variables.

Findings from mediation model studies have also been mixed. Bunford and colleagues (2015) found that hyperactivity/impulsivity symptoms of ADHD appear to mediate the relationship between inhibition and social functioning, whereas inattentive symptoms of ADHD mediate the relationship between working memory and social functioning. Similarly, Hilton and colleagues (2017) found that ADHD-related attention problems mediate the relationship between working memory deficits and social problems. In contrast, Tseng and Gau (2013) found that working memory, but not inhibition, mediates the relationship between ADHD symptoms and social problems. Limitations of previous studies include multicollinearity between working memory and stop-signal inhibition metrics (Verbruggen & Logan, 2008; Gordon & Caramazza, 1982; Kofler et al., 2018), use of simple span working memory tasks (Engle, 2010; Egeland, 2015), and use of an inhibition metric from the Stockings of Cambridge spatial planning test (Tseng & Gau, 2013), which all obscure inferences about the relative contributions of working memory and inhibitory processes to ADHD-related social problems.

Finally, it is notable that much of previous literature has focused on behavioral inhibition and working memory, in lieu of self-control. Self-control warrants consideration, however, due to meta-analytic findings that suggest children with ADHD exhibit moderate-magnitude deficits of self-control/delayed gratification relative to typically developing peers (Patros et al., 2016), and reliable findings from extant research that suggests self-control is significantly associated with interpersonal skills (Finkel & Campbell, 2001) and social acceptance among peers (Feldman et al., 1995; Ferrer & Krantz, 1987).

The study aims to explore the relative contributions of self-control, behavioral inhibition, and working memory to ADHD-related social problems. Notably, the proposed study adds to the current body of literature due to its use of a GNG inhibition metric and working memory tasks with high central executive demands. Use of the GNG task is expected to reduce multicollinearity with the working memory task (Verbruggen & Logan, 2008; Gordon & Caramazza, 1982), and consequently allow for stronger inferences about the relative contributions of inhibition and working memory to ADHD-related social functioning. Likewise, the working memory task used in this study has been shown in previous studies to place high demands on central executive processes (Rapport et al., 2008; Alderson et al., 2013; Alderson et al., 2015), and is therefore expected to provide a more valid metric of ADHD-related impairments. Finally, the study is also unique in that it is the first to examine the potential mediating role of self-control deficits in children with ADHD and their effects on social functioning.

Hypotheses

Hypothesis 1 (Intercorrelations)

Significant large-magnitude bivariate correlations were expected between the predictor variable (i.e., ADHD vs. TD), mediators (i.e., working memory, behavioral inhibition, and self-control), and the criterion variable (i.e., social functioning). Specifically, group membership was expected to be significantly associated with all mediators and the criterion variable based on findings from previous studies (Alderson et al., 2010). Moreover, low working memory scores were predicted to be negatively correlated with more commission errors (errors reflect poorer inhibition). This hypothesis was based on findings of significant correlations between inhibition and working memory across age ranges (Sonuga-Barke et al., 2002; Brocki et al., 2008; Alderson et al., 2010). Working memory scores were further predicted to be positively correlated with self-control, based on previous findings of significant correlations between working memory and self-control (Patros et al., 2017; Rapport et al., 2009; Schweitzer & Sulzer-Azaroff, 1995). Similarly, low behavioral inhibition scores were predicted to be positively correlated with less self-control, based on previous findings of significant correlations between behavioral inhibition and self-control (Katzir et al., 2021; de Ridder et al., 2012; Milyavskaya & Inzlicht, 2018; Tangney et al., 2004). Based on previous studies that have found significant correlations between inter-raters (Dekker, 2003), parent and teacher ratings were predicted to be positively correlated. Lastly, based on previous studies, low working memory was expected to be positively correlated with low social functioning (Kofler et al., 2011; Abikoff, 2009; Mikami et al., 2014; Mikami et al., 2017), impaired behavioral inhibition was expected to be positively correlated with low social functioning (Barkley, 1997; Nijmeijer et al., 2008), and less self-control was expected to be positively correlated with low social functioning based on previous research (Sonuga-Barke, 2003; Sonuga-Barke et al., 2010).

Hypothesis 2 (Simple Mediation Analyses)

Working memory, behavioral inhibition, and self-control were all expected to significantly mediate the indirect effect between group membership and both parent and teacher social problems when examined separately. These hypotheses were based on previous findings that suggest executive functions act as mediators between ADHD core symptoms, which could allude to group membership that this study utilizes, and social problems (Bunford et al., 2015; Hilton et al., 2017).

Hypothesis 3 (Multiple Mediation Analyses)

With all three executive functions included in a mediation model, working memory was predicted to be the only significant mediator of the indirect effect of group membership on parent ratings of social functioning. Similarly, with all three executive functions included in the model, working memory was predicted to be the only significant mediator of the indirect effect of group membership on teacher ratings of social functioning. These hypotheses were based on past findings that suggest impaired self-control decision making processes are downstream of working memory deficits (Patros et al., 2015), and that behavioral inhibition deficits may be attributable to working memory impairments (Alderson et al., 2010).

CHAPTER II

METHODOLOGY

Participants

The study included 121 children between the ages of 8 and 12 years recruited by posting flyers at community businesses, visiting local organizations, communicating with local parent–teacher organizations, and communicating with faculty/staff at Oklahoma State university. Fifty-eight (17.2% female) participants comprised the ADHD group and had an average age of 9.29 (*SD* = 1.52) years. The typically developing (TD) group included 63 (23.8% female) participants with an average age of 9.46 (*SD* = 1.38) years. All parents and children provided written consent and assent, respectively, to participate in the study. Institutional Review Board (IRB) approval was obtained prior to the study's onset and was maintained throughout data collection. Families received an individualized comprehensive psychoeducational report that detailed results and recommendations from the clinical assessment that was used to group participants.

Group assignment

Parents and children were administered a psychosocial interview that assessed family, social, developmental, educational, and medical history, as well as the Kiddie Schedule for Affective Disorders and Schizophrenia-Present and Lifetime Version (K-SADS-PL; Kaufman et al., 1997) that assessed onset, course, duration, severity, and frequency of symptoms associated with behavioral, affective, substance use, anxiety, and psychotic disorders. The Child Symptom Inventory-4 Parent Checklist and Teacher Checklist (CSI-4: Parent Checklist, CSI-4: Teacher Checklist; Gadow & Sprafkin, 1997), as well as the Conners 3-Parent & Teacher (C3P and C3T; Conners, 2008) scales, were also administered to identify the presence and severity of ADHD symptoms and rule-out other possible psychopathology.

Children were included in the ADHD group if they met the following criteria: (1) evidence of ADHD consistent with DSM-5 (American Psychiatric Association, 2013) diagnostic criteria provided by the K-SADS-PL; (2) clinically significant ratings by parents on the CSI-4 Parent Checklist (i.e., ≥ 6 for either the ADHD Hyperactive/Impulsive Presentation or the ADHD Inattentive Presentation or ≥ 12 for the ADHD Combined Presentation) or C3P's DSM-ADHD scale; (3) clinically significant ratings by teachers on the CSI-4 Teacher Checklist (i.e., ≥ 6 for either the ADHD Hyperactive/Impulsive Presentation or the ADHD Inattentive Presentation or ≥ 12 for the ADHD Combined Presentation) or C3T's DSM-ADHD scale.

Children were included in the TD group if they met the following criteria: (1) did not meet DSM-5 diagnostic criteria for any disorder provided by the K-SADS-PL; (2) normal developmental history (e.g., met developmental milestones, no medical complications) based on the semi-structured psychosocial interview; and (3) normal range ratings on the DSM scales of the CSI-4 Parent Checklist, CSI-4 Teacher Checklist, C3P, and C3T.

Children were excluded if they had a (1) history of a seizure disorder, (2) psychosis, (3) gross neurological, sensory, or motor impairment, (4) met criteria for another disorder but not ADHD, or (5) a Wechsler Intelligence Scale for Children (WISC) Fourth (Wechsler, 2003) or Fifth Edition (Wechsler, 2014) Full Scale IQ (FSIQ) score of less than 80.

Measures

Psychosocial Interview

A psychosocial interview was conducted with a child's caregiver/s to gather information about developmental/medical history, educational history, family history, and social functioning.

Clinical Interview

The Kiddie-Schedule for Affective Disorders and Schizophrenia, Present and Lifetime Version DSM-5 (K-SADS-PL; Kaufman et al., 1997), a semi-structured clinical interview that obtains information about current and lifetime symptoms of various disorders was administered. The interrater reliability from the original test sample for the KSADS-PL when assigning 10 current and 14 lifetime diagnoses to children was 98% for both present and lifetime diagnoses (Kaufman et al., 1997). The test-retest reliability from the original test sample was found to be good to excellent for ADHD, generalized anxiety, conduct, oppositional defiant, major depression, bipolar disorder, and post-traumatic stress disorder (Kaufman et al., 1997).

ADHD Ratings

The Child Symptom Inventory-4 Parent Checklist and Teacher Checklist (CSI-4: Parent Checklist, CSI-4: Teacher Checklist; Gadow & Sprafkin, 1997) and Conners 3-Parent & Teacher (C3P and C3T; Conners, 2008) were administered to obtain information on the severity of ADHD symptoms. Sprafkin and colleagues (2002) found acceptable to good test-retest reliability for the CSI-4: Parent Checklist and CSI-4: Teacher Checklist for both symptom severity scores and symptom count scores. Strong criterion validity has also been shown when the CSI-4: Parent Checklist scores were compared to clinical diagnoses from the original test sample, with the sensitivity score being .80 and the specificity score being .74 for ADHD (Gadow & Sprafkin, 1997). Strong criterion validity has been shown when the CSI-4: Teacher Checklist scores were compared to clinical diagnoses in the original test sample, with the sensitivity score being .60 and the specificity score being .86 for ADHD (Gadow & Sprafkin, 1997). Moderate to strong construct validity has been shown when the CSI-4: Parent Checklist and CSI-4: Teacher Checklist scores were compared to the scales of The Child Behavior Checklist from the original test sample, with the ADHD: Inattentive Presentation correlating with Attention Problems scale, ADHD: Hyperactive/Impulsive Presentation correlating with the Aggressive Behavior and Attention Problems scale, and the ADHD: Combined Presentation correlating with the Attention Problems scale (Gadow & Sprafkin, 1997). Furthermore, the Conners 3-Parent & Teacher, from the original test sample, has been shown to have acceptable to excellent test-retest reliability. Moderate to strong intercorrelations between tests with scales that measure similar constructs and the Conners 3-Parent & Teacher (convergent validity) and smaller correlations between scales of dissimilar constructs and the Conners 3-Parent & Teacher (divergent validity) have also been shown from the original test sample (Conners, 2008).

Social Ratings

The social functioning of children was assessed by the Child Behavior Checklist (CBCL; Achenbach & Rescorla, 2001) and Teacher Report Form (TRF; Achenbach & Rescorla, 2001), which both include 11 items that comprise the Social Problems narrow band scale. Achenbach and Rescorla (2001) found good test-retest reliability for the Social Problems narrow band scale on the CBCL (0.90) and TRF (0.95) and good internal consistency for the Social Problems narrow band scale (CBCL = .82; TRF = .82). Content validity has been supported for the problem item scales (i.e., an initial item pool was established through clinicians and research and appropriate revisions were made after pilot studies). The criterion validity has been supported for the CBCL and TRF through comparing the CBCL and TRF ratings to other well-established parent and teacher ratings. Lastly, the construct validity has been supported for the CBCL and TRF by the clinical sample scoring higher than the nonclinical sample (Gomez et al., 2014).

Self-Control (SC) task

Self-control was measured via a choice-impulsivity task (see Patros et al., 2015) and was programmed in Microsoft Visual Basic (Saradhara, 1991) software. Two 3.81 x 2.54cm boxes were placed horizontally on a touch screen monitor, with the left box representing a smaller point value and shorter delay schedule of reinforcement (1 point, 2 s), and the right box representing a greater point value and longer delay schedule of reinforcement (20 points, 30 s). Figure 1 provides a visual schematic of the self-control task. The task is programmed so that choosing the larger, delayed option will always yield the greatest total reinforcement density. The reinforcement schedules were not counterbalanced across trials since previous research suggests choice-impulsivity responses are not affected when response options are presented from least to greatest or greatest to least (Logue et al., 1990). Children were given continuous feedback on total points earned through a counter located at the top center of the screen. Two practice trials were completed, with the left and right box being pressed one time to help the children become acquainted with the nature of the task. After the practice trials, children were told to use one finger on their dominant hand to pick between the two options. They were told the goal was to earn as many points as they could and that points could be traded for a prize following completion of the task, with the quality of the prize contingent on the amount of points they obtained (i.e., more points = better prize). The prize was not revealed until the task was completed, as previous research suggests that "mystery" reinforcers help increase reinforcement potential and anticipation (Rhode et al., 1993). Children engaged in the task for ten minutes and the total points children earned served as the dependent variable of the task, with more impulsive responding being associated with fewer points.

Go/No-Go (GNG) Task

The go/no-go task described in Tarle et al. (2019) was used in this study as a metric of behavioral inhibition. Letters in bold Times New Roman font and 4.0 cm tall were shown one at a time for 1,000 ms at the center of a computer screen. A 1000 ms inter-stimulus interval occurred between each letter presentation. Children were instructed to click the left button on a mouse as fast as possible after seeing a letter (go-stimulus; e.g., A, B, C) appear on the screen, except if the letter Y was presented (i.e., no-go stimulus). Children engaged in one practice block to allow for the researcher to correct mistakes instantaneously and to ensure they understood the task. After the practice block, three consecutive experimental blocks were completed, with each block consisting of 24 go trials and 8 no-go trials (96 total experimental trials). The GNG task yielded several variables including the mean reaction time (MRT) to go stimuli, the standard deviation of mean reaction time (SDRT), and total commission errors that served as the metric for response inhibition. Figure 2 provides a visual schematic of the go/no-go task.

Phonological (PH) Working Memory Task

The Phonological Working Memory (PHWM) task was programmed using SuperLab 4.0 (Assessment System Corporation, 2008) and is similar to the Letter-Number Sequencing subtest in the Wechsler series of intelligence tests (Wechsler, 2003). The PHWM task is a modified version of a measure developed by Rapport et al. (2008) and was designed to assess phonological working memory based on Baddeley's (2007) model. Children heard a series of single-digit numbers and one letter taken from a prerecorded stimulus bank. No number was presented twice in the same trial. The serial position of the letter in the sequence of stimuli (i.e., Position 2, 3, 4, or 5) was counter-balanced across trials to occur equally, but the letter never appeared in the first or last position of the sequence to reduce potential primacy or recency effects. Each number or letter was followed by a 200 ms interstimulus interval, and each trial was followed by an auditory "click" and the appearance of a green traffic light, displayed on a 17- by 14-inch touchscreen monitor, to signal the child should give a verbal response.

Children were instructed to recall the numbers aloud from smallest to largest followed by the letter. After verbally responding, children touched the computer screen to advance to the next trial. Children were allowed 10 seconds per stimulus to respond (e.g., 40 seconds during trials of four stimuli, 50 seconds during trials of five stimuli). If a child did not make a response during this time, the next trial was automatically presented. Responses were followed by an intertrial interval of 1000 ms and an auditory click to signify the beginning of a new trial. Trials were comprised of three to six stimuli (i.e., set sizes of 3, 4, 5, and 6), and each set-size block consisted of 24 trials (96 total trials). Figure 3 provides a visual schematic of the phonological task. The presentation order of set-size blocks was counterbalanced across children. Five practice trials were administered prior to the experimental trials, and children were required to respond correctly to 80% of the practice trials to proceed. Children's verbal responses were independently coded by two research assistants in an adjacent room (outside of the child's view). Children did not receive feedback about their performance during practice or experimental trials. The average number of stimuli correctly recalled per trial for each of the four stimulus set sizes (i.e., phonological composite score) represented the dependent variable.

Procedure

Children completed two clinical sessions that included a clinical interview, psychosocial interview, and assessment of intellectual functioning and academic achievement. Parent and teacher behavioral rating scales were attained before the first clinical session. Two to three total research sessions on separate days were held after the clinical sessions to complete the self-control, behavioral inhibition, and working memory tasks, which were administered as part of a larger battery of experimental tasks that were counterbalanced across research sessions. Each session lasted approximately 3 hrs. Each child was allowed short breaks after every two to three tasks to help with fatigue reduction.

Data analytic strategy

IBM statistics package for the Social Sciences (SPSS) version 28 (IBM Corp, 2021) was used to conduct statistical analyses. Tier I included independent samples *t*-tests and Pearson's chi-square tests that were used to analyze demographic data and descriptive statistics. Intercorrelations between the predictor variable (i.e., group, ADHD vs. TD), mediators (i.e., working memory, behavioral inhibition, and self-control), and the criterion variable (i.e., social functioning) were then examined in Tier II. Next, six bias-corrected bootstrapped single mediation analyses were conducted in Tier III, using the PROCESS macro model 4 (Hayes, 2017), to examine the potential indirect effect of group, through each EF, on parent ratings of children's social functioning. This procedure was repeated with teacher ratings of children's social functioning as the criterion variable. Finally, four multiple mediation models (i.e., two for parent and two for teacher ratings) were planned for Tier IV analysis, such that all significant mediators identified in Tier III would be included. The planned Tier IV analysis aimed to examine the extent to which working memory, inhibition, and self-control served as predictors of unique variability in ADHD-related social functioning difficulties.

Use of the bootstrapping procedure has been shown to reduce potential Type II errors associated with small samples, without proportionately increasing risk of Type I errors (Preacher & Hayes, 2004). The bootstrap procedure is also an appropriate method to examine mediation effects with samples as small as 20 participants (Efron & Tibshirani 1993; Preacher & Hayes 2004); however, Fritz and MacKinnon (2007) suggest that 71 participants are needed to reliably detect significant effects and reject H_0 when the magnitude of both *a* and *b* paths of bootstrapped mediation models are medium. This study’s sample included 121 children, which suggests it was sufficiently powered. Five-thousand re-samples were derived using a re-sampling process with replacement from the original sample, as suggested by Shrout and Bolger (2002). Significant indirect effects were detected using 95% confidence intervals of the sampling distribution of the mean, and were indicated by confidence intervals that did not include zero.

CHAPTER III

RESULTS

Outliers

Predictor and criterion variables were screened for univariate outliers prior to running analyses. Outliers were defined as values at least 3.29 standard deviations above or below the mean for each group (i.e., $p < .001$; Tabachnick & Fidell, 2001). Outliers were replaced with a value equal to ±3.29 standard deviations from the mean (i.e., two values replaced in the Phonological Set Size Three variable, three values replaced in the Teacher Report Form variable, one value removed in the Self Control variable because wrong reported value in data, and one value replaced in the Go/No-Go Total Commission Errors variable).

Grouping and Demographic Variables

Children in the ADHD group did not differ from children in the TD group with regards to age, $t(119) = .63$, $p = .53$, sex, $t(119) = .89$, $p = .38$, or ethnicity $\chi^2(4) = 8.95$, $p = .06$, and consequently, those variables were not included as covariates. Total parent income and average level of education attained by parents were used as proxies for socioeconomic status (SES; Bradley & Corwyn, 2002; Parent education was coded on a 7-point scale adopted from Hollingshead (1975; 1 = less than 7th grade, 2 = junior high [9th grade], 3 = partial high school [10th or 11th grade], 4 = high school graduate, 5 = partial college, 6 = college/university degree, 7 = graduate degree). The average total family income of children with ADHD was not statistically different from the average total family income of children in the TD group, $t(72) = .54$, $p = .59$ (total parent income data for 38 children were missing). Parents of children in the ADHD group attained lower average levels of education compared to parents of children in the TD group, χ^2 (3) = 7.66, $p = .05$ (in the case that data were provided for both mother and father, data from the parent with the highest level of education was used; level of education data for 1 child was missing). The SES proxy variables were not included as covariates, however, due to the high correlation between ADHD and SES (Rowland et al., 2018; Russell et al., 2016), and the strong potential for removing ADHD-related variability when covarying SES scores. Finally, children in the ADHD group had a lower mean FSIQ than children in the TD group, $t(114) = 4.63$, $p < .001$. FSIQ was not included as a covariate due to the well-documented strong association between working memory and FSIQ (Wechsler, 2003), and the likelihood that covarying FSIQ would remove variability associated with a primary variable of interest (Ackerman et al., 2005). Demographic data are shown in Table 1.

Intercorrelations

Table 2 displays intercorrelations among group membership (ADHD or TD), executive functions (i.e., working memory, behavioral inhibition, and self-control), and social functioning. Group membership was significantly correlated with the phonological (PH) composite score ($p < .001$), total commission errors ($p = .04$), total points earned on the self-control task ($p = .04$), and parent ($p < .001$) and teacher ($p < .001$) ratings of child social functioning. The PH composite score was significantly positively correlated with the total points earned on the self-control task ($p < .001$) and significantly negatively correlated with total commission errors ($p = .01$). The total commission errors, however, were not significantly correlated with the total points earned on the self-control task ($p = .59$). Parent ratings of child social functioning were significantly positively correlated with teacher ratings of child social functioning ($p < .001$). Further, parent ratings of child social functioning were significantly negatively correlated with the PH composite score ($p = .02$) but not significantly correlated with total commission errors ($p = .50$) or the total points earned on the self-control task ($p = .57$). Similarly, teacher ratings of child social functioning were significantly negatively correlated with PH composite score ($p < .001$) but not significantly correlated with total commission errors ($p = .46$) or the total points earned on the self-control task ($p = .11$).

Bootstrapped Mediation Analyses

Examination of potential indirect effects with the bootstrapping procedure indicated that the relationship between the grouping variable (ADHD, TD) and teacher ratings of child social functioning was significantly mediated by PH composite score ($M_ß = 0.37$, *S.E.* = 0.16, 95% CI = 0.08 to 0.71). The PH composite score, however, did not significantly mediate the relationship between the grouping variable (ADHD, TD) and the parent rating of child social functioning ($M_ß = 0.04$, *S.E.* = 0.22, 95% CI = -0.36 to 0.50). Total commission errors on the GNG task did not significantly mediate the relationship between the grouping variable (ADHD, TD) and the parent rating of child social functioning ($M_{ß}$ = -0.03, *S.E.* = 0.12, 95% CI = -0.30 to 0.21). The total commission errors for behavioral inhibition did not significantly mediate the relationship between the grouping variable (ADHD, TD) and the teacher rating of child social functioning ($M_{ß}$ = -0.02, *S.E.* = 0.09, 95% CI = -0.23 to 0.16). Lastly, the total points earned in the self-control task did not significantly mediate the relationship between the grouping variable (ADHD, TD) and the parent rating of child social functioning ($M_{ß}$ = -0.09, *S.E.* = 0.18, 95% CI = -0.44 to 0.30). The total points earned in the self-control task did not significantly mediate the relationship between the grouping variable (ADHD, TD) and the teacher rating of child social functioning ($M_{ß}$ = 0.09, *S.E.* = 0.14, 95% CI = -0.13 to 0.45). Standardized beta weights (interpreted as Cohen's d effect sizes), SE, and 95% confidence intervals for all bootstrap analyses of the indirect effects are displayed in Table 3.

Multiple Mediation Analysis

Although multiple mediation analyses were planned, they were not conducted since only PH working memory was a significant mediator when examined alone.

CHAPTER IV

DISCUSSION

The current study examined self-control, behavioral inhibition, and working memory as potential mediators of the relationship between group membership and social functioning. Notably, this was also the first study to examine the potential mediating role of self-control deficits in children with ADHD and their effects on social functioning. As a first step, intercorrelations were assessed between group membership, self-control, behavioral inhibition, working memory, and parent and teacher rated social functioning. As expected, group membership was significantly associated with parent and teacher ratings of social functioning, such that children with ADHD compared to typically developing children score higher on social problems when rated by parents and teachers. Furthermore, group membership was significantly associated with each executive function, such that children with ADHD exhibit worse performance on self-control, behavioral inhibition, and working memory tasks than typically developing children. The significance of group membership with the mediators and criterion variable is consistent with previous literature (Alderson et al., 2010).

Our finding that working memory scores were positively correlated with self-control, such that lower working memory scores were associated with lower self-control scores, is supported by previous literature (Patros et al., 2017; Rapport et al., 2009; Scweitzer & Sulzer-Azaroff, 1995). Contrastingly, working memory scores were negatively correlated with behavioral inhibition, meaning lower working memory scores were associated with higher behavioral inhibition scores (i.e., more total commission errors mean less inhibition), which is in line with the literature (Sonuga-Barke et al., 2002; Brocki et al., 2008; Alderson et al., 2010). Moreover, parent and teacher ratings of social functioning were positively correlated as found in previous studies (Dekker, 2003). Both parent and teacher ratings of social functioning were significantly negatively correlated with working memory, meaning higher ratings of social functioning problems were associated with lower working memory abilities, which is consistent with previous literature (Kofler et al., 2011; Abikoff, 2009; Mikami et al., 2014; Mikami et al., 2017).

Contrary to expectations based off findings from previous studies, behavioral inhibition and self-control were not significantly correlated (Katzir et al., 2021; de Ridder et al., 2012; Milyavskaya & Inzlicht, 2018; Tangney et al., 2004) and parent and teacher ratings of social functioning were not significantly correlated with behavioral inhibition or self-control (Barkley, 1997; Nijmeijer et al., 2008; Sonuga-Barke, 2003; Sonuga-Barke et al., 2010). The lack of the relationship between behavioral inhibition and parent and teacher ratings of social functioning may be because other studies used measures besides the GNG task, which reduces multicollinearity with the working memory task. Moreover, the lack of significant correlations for self-control (besides working memory) may be because the self-control measure had a smaller sample size than the other executive function metrics (n = 79 vs. n = 118 or 119) as the task was added later to the lab battery.

Mediation analyses were done to examine the potential indirect effect of group, through each executive function, on parent ratings of children's social functioning as well as on teacher ratings of children's social functioning. Examinations revealed that working memory significantly mediated the effect of group membership (ADHD, TD) on teacher ratings of children's social functioning. Working memory, however, did not significantly mediate the relationship between group membership and parent ratings of children's social functioning. These findings are consistent with recent findings of working memory effects on teacher-rated social functioning (Kofler et al., 2011; Kofler et al., 2018). However, these studies also found support for working memory effects on parent-rated social functioning, which the current study did not. The phonological working memory task (Baddeley, 2007; Rapport et al., 2008) was utilized to provide a more valid metric of ADHD-related impairment, which could explain why results differed. Moreover, the current study's insignificant findings for parent ratings may be because working memory is a limited resource, and in an academic environment, where resources are being used for learning, fewer resources are able to be utilized in engaging in appropriate social functioning (Phillips et al., 2007). Reducing task demands in the classroom has been found to help decrease disruptive and off-task behavior, which, in turn, could affect how children with ADHD socialize (DuPaul & Stoner, 2003; DuPaul et al., 2011). Another potential explanation is that parents may not see the same social deficits that teachers see because of the different activities one is engaging in at home compared to at school. For example, when one is at home, there is less opportunity for social engagement and, thus, fewer social deficits may be perceived by parents. There is more opportunity for social interaction at school, which may lead to lower ratings of social skill abilities by teachers.

Support for this idea comes from previous research that has suggested that parents perceive a reduction in their child's ADHD symptoms in natural environments with more room to move and play (van Der Berg & van Der Berg, 2010).

Moreover, the findings that behavioral inhibition did not mediate the relationship between group membership and both parent and teacher ratings of children's social functioning is consistent with more recent findings in the literature. For example, Kofler and colleagues (2018) and Tseng and Gau (2013) did not find support for behavioral inhibition as a significant predictor of ADHD symptoms and social functioning. This study used an inhibition metric (i.e., GNG task) that reduced multicollinearity with the working memory task and examined the independent contribution of inhibition and working memory. Findings suggest that behavioral inhibition may not play a role in ADHD symptoms or social functioning related deficits as previously expected (Alderson et al., 2012). Lastly, it was found that self-control did not significantly mediate the relationship between group membership and both parent and teacher ratings of children's social functioning. This provides support for self-control deficits being downstream of working memory deficits as found in Patros and colleagues' (2015) study. This a notable finding since this was the first study to examine the potential mediating role of self-control deficits in children with ADHD and their effects on social functioning.

There are some potential limitations to this study. Smaller sample sizes, overall, are more at risk for Type II errors. However, this study utilized bias-corrected bootstrapped mediation analyses to reduce potential Type II errors without proportionately increasing Type I errors (Preacher & Hayes, 2004) and followed Fritz and MacKinnon's (2007) recommendation of 71 participants needed to reliably detect significant effects and reject H_0 when the magnitude of both *a* and *b* paths of bootstrapped mediation models are medium. However, a larger sample size would be beneficial to see if results replicate and/or allow for discovery of other significant findings. Moreover, the sample had a smaller number of girls compared to boys. This is not unexpected as girls, especially with the inattentive presentation of ADHD, are less likely to be signified as needing a clinical evaluation (Coles et al., 2012; Sciutto et al., 2004). A more diverse sample, with the addition of female participants, would help to examine if the results generalize to the broader population of children.

While this study may have potential limitations, there are also many strengths within this study. For instance, the children in this study received a thorough clinical evaluation to obtain their diagnoses, which helps in strengthening the ADHD-related findings. Moreover, this study used a working memory task with high central executive demands, which allows for clarification regarding the inconsistencies in measuring working memory in previous studies. Through the utilization of clear methodology, this study was able to find that working memory specifically plays a role in social functioning in children with ADHD. Furthermore, the findings suggest that it may be beneficial to target working memory in interventions for children with ADHD in order to help improve their social functioning abilities. Future directions for the study include examining other components of working memory besides phonological working memory (e.g., visuospatial working memory, the episodic buffer) as well as engaging in direct observation of social functioning in children with ADHD who are participating in a working memory intervention. Moreover, the use of more than one social functioning measure could be implemented to provide an even broader scope of social functioning abilities. Lastly, the study could be performed with a new sample of varying ages and genders to ensure replication of findings.

Overall, this study provided support for working memory mediating the relationship between group membership (ADHD vs TD) and social functioning. Findings did not support behavioral inhibition or self-control as mediators for the relationship between group membership (ADHD vs TD) and social functioning. This study adds important findings to the literature as it uses methodology that allows for the roles of the different executive functions to be parsed apart (i.e., the use of the GNG inhibition metric with less multicollinearity with working memory, a working memory task with a high central executive demand). Moreover, this study was the first to examine the role of self-control in ADHD-related social functioning deficits. Findings from this study suggests that more research related to working memory is needed in order to help target interventions to assist social functioning deficits in children with ADHD.

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APPENDIX

Review of Literature

Attention-deficit/hyperactivity disorder (ADHD) is a neurodevelopmental disorder characterized by symptoms of hyperactivity, impulsivity, and/or deficits of attention (Sagar et al., 2017), and is estimated to be prevalent among 3-7% of school-aged children (Lee et al., 2008; Selikowitz, 2009). There are three presentations of ADHD: an inattentive presentation, a hyperactive-impulsive presentation, and a combined presentation. The inattentive presentation of ADHD has a typical age of onset around high school, occurs in approximately an equal number of boys and girls, and is the most common subtype diagnosed in adulthood. The hyperactive-impulsive presentation of ADHD, in contrast, has an age of onset in the preschool to elementary school years and is more common in boys than girls (Leon, 1997; Waschbusch et al., 2007; Selikowitz, 2009; Willcutt, 2012). Children with the inattentive presentation struggle with sustaining attention/concentration, completing tasks, and being forgetful and disorganized (Capriotti & Pfiffner, 2019; Haack et al., 2017). Daydreaming, confusion, and losing homework and/or school supplies is also common among children with the inattentive presentation (Leon, 1997; Mueller et al., 2014). Children with the hyperactive-impulsive presentation exhibit impulsive behaviors and excessive motor activity (Selikowitz, 2009). Examples of symptoms associated with this presentation include fidgeting, squirming, and talking excessively at inappropriate times in class

The combined presentation of ADHD includes features from both the inattentive and hyperactive-impulsive presentations and is most commonly seen in elementary school aged children as well as in clinical practice (Willcutt, 2012).

Mixed evidence has been offered for the validity of multiple ADHD presentations. For example, some children with ADHD exhibit a varying course of ADHD symptoms over time, which appears to suggest the ADHD presentations are unstable and distinct only when symptoms are measured (Lahey & Willcutt, 2010). Inattention features of existing diagnostic criteria lead to heterogeneity such that some individuals may be better classified as having ADHD-C while others present as ADHD-I (Milich et al., 2001). Even more, Willcutt et al.'s (2012) meta-analytic review found that, although symptoms of ADHD are dimensional, subtypes/presentations are pragmatically useful in clinical settings, allowing for ease of explanation to clients. To that end, performance on neuropsychological and cognitive tasks is often more similar than different among the subtypes (Adams et al., 2010; Barkley & Murphy, 2011; Derefinko et al., 2008; Lemiere et al., 2010). On the other hand, factor analytic studies suggest that a three-factor structure consisting of inattentiveness, hyperactivity, and impulsivity exists for ADHD (Glutting et al., 2005; Proctor & Prevatt, 2009). There is more support for ADHD-I and ADHD-C as distinct subtypes, however, compared to ADHD-HI (Baeyens et al., 2006; Bauermeister et al., 2005; Lemiere et al., 2010; Woo & Rey, 2005).

History of ADHD

George Still first described a condition of children that included hyperactive and concentration difficulties in 1902 (Selikowitz, 2009). Interest in symptoms related to this condition, including restlessness, distractibility, and impulsivity, piqued with the emergence of postencephalitic behavior disorder following the encephalitis epidemic of 1917-1918 (Barkley, 2006; Smoyak, 2008; Millichap, 2009). Children that displayed these symptoms during the 1950s and 1960s were regularly hospitalized in psychiatric facilities and were categorized under the label of minimal brain dysfunction because brain damage was inferred from these symptoms (Barkley, 2006; Eisenberg, 2007; Smoyak, 2008).

The term *hyperkinetic reaction of childhood* was subsequently included in the Diagnostic and Statistical Manual, 2nd Edition (DSM-II; American Psychiatric Association, 1968; Millichap, 2009; Epstein & Loren, 2013), and was used to describe excessive motor activity that was theoretically associated with a deficit in the thalamic region of the central nervous system (Barkley, 2006; McGough, 2014).

Douglas (1972) contrastingly proposed that attention was the central deficit of the disorder and hyperactivity was only a commonly associated symptom that was not necessary for diagnosis. This view led to the disorder being renamed attention deficit disorder (ADD) with or without hyperactivity in the Diagnostic and Statistical Manual, 3rd Edition (DSM-III; American Psychiatric Association, 1980; Millichap, 2009; Epstein & Loren, 2013). The with or without hyperactivity subtypes were created in an attempt to increase the clinical utility of diagnoses (Rubinstein & Brown, 1984).

Mixed evidence was found for the two subtypes, with some studies indicating little significant difference (Maurer & Stewart, 1980; Rubinstein & Brown, 1984) and others illuminating variability in behavior and cognitive and motor tests (King & Young, 1982; Berry et al., 1985). Ultimately, the ADD with hyperactivity moniker was replaced with Attention Deficit/Hyperactivity Disorder in the Diagnostic and Statistical Manual, 3rd Edition, Revised (DSM-III-R; American Psychiatric Association, 1987; Barkley, 2006; Epstein & Loren, 2013), and later, the predominantly inattentive, predominantly hyperactive-impulsive, and combined subtypes were added in the Diagnostic and Statistical Manual, 4th Edition (DSM-IV; American Psychiatric Association, 1994) and Diagnostic and Statistical Manual, 4th Edition, Text Revision (DSM-IV-TR; American Psychiatric Association, 2000; Epstein & Loren, 2013; Millichap, 2009; Parker, 2005). Notably, hyperactivity and impulsivity were collapsed into one subtype based on evidence from factor analytic studies suggesting the change from a one- to two-dimensional symptom group (Bernfeld, 2012). Finally, publication of the Diagnostic and Statical Manual, 5th Edition (DSM-V; American Psychiatric Association, 2013) included several revisions to the ADHD diagnostic criteria and moniker. For example, the qualifier "subtype" was replaced with "presentation" to better characterize fluidity and changes in the phenotypic expression of ADHD that can occur across the lifespan (Carrascosa-Romero & De Cabo-De La Vaga, 2015). Further, severity modifiers were added to allow for greater specificity (Epstein & Loren, 2013), and the age of onset was increased to 12 years to aid in the lack of diagnosing children who encounter impairment at a later age (i.e., those with primarily inattentive symptoms, high intelligence, or those in a highly structured environment; Epstein & Loren, 2013; Austerman, 2015). Lastly, the presence of symptoms in at least two settings were added as a requirement for the disorder so that the behavior is happening in more than one place (Austerman, 2015).

Negative Outcomes Associated with ADHD

Many negative outcomes are commonly associated with inattention and impulsivity symptoms of ADHD in children. For example, academic functioning is often impaired in children with ADHD in part because affected children have trouble paying attention and finishing instructed tasks, causing them to complete schoolwork with less accuracy, to earn lower school grades and standardized test scores, and to be at greater risk of failing a grade or failing high school (Ingram et al., 1999; Loe & Feldman, 2007). Reading and math achievement gains throughout elementary school, in particular, tend to be smaller for children with ADHD compared to typically developing children (Rabiner et al., 2016). Moreover, children with ADHD are often disruptive in the classroom, not good at sharing or taking turns, and display delinquent behaviors, such as oppositional and conduct problems (Gardner & Gerdes, 2013). Children with ADHD also tend to take more risks due to their impulsivity traits and are not as conscientious or concerned about the consequences that may occur because of those risks (Weafer et al., 2011).

Academic struggles carry over into adolescence and adulthood (Daley & Birchwood, 2009), with adverse effects on occupational outcomes such as lower rates of post-high school education, lower vocational status, and unemployment (Kuriyan et al., 2013). Individuals with ADHD also tend to experience more driving problems, such as being involved in more accidents and having more license suspensions and traffic violations, compared to those without ADHD (Thompson et al., 2007). Family functioning is also frequently negatively affected by ADHD due to greater family conflict and more negative communication (Markel & Wiener, 2014; Haydicky et al., 2015), and marriages tend to include more conflict, communication difficulties (listening problems), and higher divorce rates than marriages between individuals without ADHD (Ersoy & Topçu Ersoy, 2019). Finally, children (Erhardt & Hinshaw, 1994; Humphreys et al., 2016), adolescents (Bagwell et al., 2001; Kofler et al., 2015), and adults (Friedman et al.,

2003) with ADHD tend to experience a myriad of social problems due to their noncompliant, disruptive, and aggressive behaviors that often result in rejection by peers and ultimately fewer friendships.

A General Overview of Social Functioning

Social functioning is a nebulous construct that has little agreement with respect to how it is defined in extant literature (John, 2001). For example, one definition of social functioning refers to performance across a number of domains, such as employment, interpersonal relations, recreation, and independent living (Green, 1996; Yager & Ehmann, 2006), while another definition suggests social functioning encompasses the social skills necessary to perform social roles (Priebe, 2007). Another broader definition of social functioning defines the construct as a range between social competence (i.e., the ability to adapt behavior in a specific context to attain social goals and social demands; Iaroccci et al., 2007) and impairment (i.e., deficits in social cognition, social outcomes, and social behavior, which may be indicated in social competence; Nixon, 2001; Morris et al., 2021).

Despite subtly varying definitions of social functioning across published studies, models of social functioning often define the construct within the context of an assessment of performance and skills across social situations. For example, the social information processing (SIP) model describes problem-solving stages (i.e., understanding cues, simplifying goals, producing multiple responses, choosing and initiating a response, and observing the outcome) that are associated with variation in how social information is managed in the brain when an individual is trying to adapt to social demands (Crick & Dodge, 1994). Expansions of the SIP model have emphasized cognitive, behavioral, and emotional predictors of social competence in relation to peer acceptance (Guralnick, 1992; Guralnick, 1999; Mostow et al., 2002), as well as aggressive behavior as a potential predictor of a contextual social cognitive model (Lochman & Wells, 2002). Moreover, emotional processing and moral theory have been added to the conceptualization of the SIP model (Lemerise & Arsenio, 2000; Arsenio & Lemerise, 2004).

Yeates et al.'s (2007) integrative-heuristic model proposes that social information processing consists of cognitive-executive functions, social-affective functions, and social problem-solving that in turn influences social interaction and social adjustment. For instance, a child that experiences deficits in social information processing may become more socially anxious, withdrawn, and/or aggressive when interacting with others, which typically leads to peer rejection and behaviors that promote the negative self and peer perception (Parker et al., 2006). This model also examines insult/non-insult related risk and resilient factors, and is bidirectional such that social adjustment can affect social interactions and downstream social information processing. The socio-cognitive integration of abilities model (SOCIAL; Beauchamp and Anderson, 2010) alternatively suggests that social skills are formed based on a combination of biological and environmental factors that determine the individual's ability to interact with their social environment. Finally, social learning theory states that learning happens through observing, modeling, and imitating others via a process of vicarious learning (Bandura, 1977), and children with disabilities in these areas tend to exhibit impaired social skills (Vaughn et al., 2001) and more awkward social interactions (Lamport et al., 2012).

Social problems occur when the development of social skills and functioning are not adequate or commensurate with a child's chronological age (Guralnick & Weinhouse, 1984), and are characterized by difficulties in learning from others (Travis & Sigman, 1998), impaired communication skills (Chen, 2006), developmentally inappropriate awareness of proper norms or cues (Elliot & Gresham, 1993), and/or impaired ability to draw upon and execute social skills when needed (Asher, 1990; Walker et al., 1995; Vaughn et al., 2009). Impaired social skills are associated with a number of negative outcomes including inadequate social networks and support (Brugha et al., 1993), increased risk for criminal behaviors in adolescence and adulthood (Kupersmidt & Coie, 1990; Hawkins et al., 2005), and significant psychiatric and neurological conditions (Beauchamp & Anderson, 2010). For instance, individuals with schizophrenia often experience difficulty accurately appraising social situations and recognizing social patterns, and struggle to utilize effective problem solving in social situations (Ikebuchi, 2007). Similarly, individuals with autism spectrum disorder often exhibit diminished interest and/or impaired effectiveness in social exchanges, forming social relationships with same-aged peers, and understanding others' nonverbal behavior (Cotugno, 2009). Not surprisingly, both anxiety and mood disorders are also associated with social skills deficits. For example, self-reported social skills of individuals with social anxiety are frequently lower than actual performance in social situations, despite concurrent subjective reports of high social discomfort (Strahan, 2003). Blunted or flat affect that regularly accompanies mood disorders such as major depressive disorder (MDD) may likewise be interpreted by others as cold or unwelcoming and consequently lead to difficulties in social interactions (Kupferberg et al., 2016). Finally, a wealth of extant findings indicate that individuals with ADHD experience persistent social functioning impairments across the lifespan (Michielsen et al., 2015).

Social functioning and ADHD

Children with ADHD regularly experience trouble forming and maintaining age-appropriate relationships (Cleminshaw et al., 2020; Morris et al., 2021), and are often rejected by their peers (Mrug et al., 2001; Hoza, 2007). ADHD-related disruptive behavior during shared activities, frequent interrupting of peers, and not actively listening and responding appropriately when in conversation contribute to chronic social difficulties in affected children (DuPaul & Weyandt, 2006). Children with ADHD do not have a lack of desire for social relations, but rather, have difficulty exhibiting appropriate behavior for a given context (Nijmeijer et al., 2008). They tend to have fewer friends overall (Bagwell et al., 2001; Hoza et al., 2005) and are less likely to be chosen by popular children (Hoza et al., 2005). Children with ADHD also tend to experience trouble taking other individual's perspectives and often hold a positive illusion of themselves and their actions/competence (i.e., a positive illusory bias; Hoza et al., 2000), which in turn negatively influences their social functioning (Gardner & Gerdes, 2013; Hoza et al., 2004). Children with ADHD can be aggressive and hostile, and commonly incorrectly assume aggressive intentions from others in situations that are neutral (i.e., a hostile attribution bias; Rosen et al., 2014). Moreover, withdrawal, anxiousness, and shyness are commonly exhibited by children with the inattentive presentation, leading to generally fewer social interactions (Nijmeijer et al., 2008). These social difficulties also negatively affect academic progress due to decreased class participation (Hamre & Pianta, 2001) and inferior teacher-student relationships, compared to same-aged peers (Rabiner et al., 2016).

A meta-analytic review of 109 studies of social functioning in children with or at risk for ADHD found evidence of significant moderate-magnitude deficits in ADHD-related peer-functioning (i.e., friendships, popularity, and peer rejection/likeability), small but significant-magnitude deficits in ADHD-related social skills (i.e., prosocial behavior and social skills performance), and small but significant-magnitude deficits in ADHD-related social information processing (i.e., positive illusory bias and hostile attribution bias; Ros and Graziano, 2018). Notably, studies that included younger children, utilized a comprehensive gold-standard diagnostic approach, and obtained reports of social functioning from peers rather than parents were associated with larger effect sizes of ADHD-related peer functioning deficits. Studies that utilized a comprehensive gold-standard diagnostic approach and observational methods as opposed to parent and teacher reports or parent rather than both parent and teacher reports were associated with larger effect sizes of ADHD-related social skills.

Finally, phenotypic variation in the ADHD presentations appears to contribute to heterogeneity in social problems. Inattention problems, for example, may contribute to difficulty understanding subtle social cues (Morris et al., 2021) and difficulties in social observational learning (Hoza, 2007). Hyperactive/impulsive symptoms may contribute to difficulties like cooperating, sharing, and taking turns (Wehmeier et al., 2010), and the combined presentation may contribute to aggressive behavior and less popularity among peers (Maedgen & Carlson, 2000).

Models of ADHD and Social Functioning

Extant models of ADHD vary with respect to the extent to which they account for ADHD-related social difficulties. Leading models of ADHD and their predictions about ADHD-related social functioning impairments are described below.

Cognitive-Energetic Model of ADHD.

Sergeant's cognitive-energetic model consists of three levels. The first level includes encoding (i.e., learning of information initially; McDermott & Roediger, 2018), central processing (i.e., searching for memories and making decisions about the memories; Sergeant, 2005), and a motor stage (i.e., examining the organization and output of the motor system; Sergeant, 2005), while the second level includes arousal (i.e., the physiological response to a stimulus that is influenced by the level and type of signal), effort (i.e., the energy required to perform tasks), and activation (i.e., the physiological readiness to respond, which is influenced by environmental variables). Effort and activation, which make up energetic functioning, have been shown to influence motor output (Sergeant et al., 1999), and energetic dysfunction may play a role in inhibition problems associated with ADHD (Sergeant, 2005). Finally, the third level in Sergeant's model includes executive functioning, such as detecting and correcting errors, planning, and monitoring (Sergeant, 2005). Sergeant's CEM does not explicitly account for ADHD social functioning impairments, but implies that energetic dysfunction leads to social functioning deficits by means of disruptive behavior and interrupting peers.

Inhibition Models of ADHD.

Behavioral inhibition is the process of disrupting/withholding or stopping an on-going response to a prepotent stimulus (Schachar et al., 2000). Logan's (1982) seminal work examined inhibition by observing the number of keystrokes that expert typists made following the introduction of a stop-signal, and noted that the typists were able to inhibit their responses one or two keystrokes after presentation of the stop signal, regardless of whether they were typing sentences or single words. These findings indicated that typing responses are processed in components that are smaller than the word. Logan (1983) subsequently refined the methodology with the use of a more rigorous task with greater experimental control. Specifically, pairs of words were presented and a category or a rhyme decision was made about the pair unless a stop signal was delivered. A participant's ability to control their thought was the focus of the experiment and was measured by a participant's memory about the words in which they had to make a decision. Findings indicated that prepotent responses are ballistic and may not always be discontinued once initiated. This suggests that actions are either stopped directly (i.e., the motor system is inhibited) or indirectly (i.e., communication between thought and action is disturbed). Logan and Cowan (1984) subsequently introduced the horse-race model of inhibition, which suggests that inhibitory success or failure depends on the relative finishing times of stochastically independent go and stop processes that are initiated in the presence of prepotent go and stop stimuli, respectively. That is, the relative speed of the stop process must overcome the relative speed of the go process to withhold or discontinue a response.

Logan and Cowan's (1984) stop-signal task (SST) is the premiere metric of behavioral inhibition used in studies of ADHD, likely due to its ability to estimate participant's covert stop-signal reaction times (SSRT; Alderson et al., 2007). In the prototypical SST, participants are instructed to quickly respond to two choice-stimuli (e.g., X or O) by pressing left and right buttons of a response pad (Verbruggen & Logan, 2008). The fast and repeated presentation of these go-stimuli serves to condition pre-potent responding. A stop-signal such as an auditory tone is intermittently presented on a subset of trials (typically 25 – 32% of total trials) and participants are instructed to withhold or stop their response in the presence of the stop-stimuli (Verbruggen & Logan, 2009). Early versions of the stop-signal task presented this paradigm across multiple blocks of trials that varied the latency between presentation of the go-stimuli and stop-signals (i.e., stop-signal delays (SSD); Osman et al., 1986; Osman et al., 1990; Schachar & Logan, 1990; Schachar et al., 1995). Commonly reported metrics of early stop-signal tasks included mean reaction times to the go-stimuli (MRT; i.e., the average time it takes to encode visual stimuli and produce a motor response), a metrics of inhibitory success/failure (e.g., percent of successful inhibition), inhibition functions, and an estimated SSRT. Logan et al. (1997) revised the stop-signal paradigm to include dynamic SSDs that allow for a more parsimonious SSRT estimation procedure and control for the tendency of participants intentionally slowing their go-reactions times to prepare for the stop-signals. Specifically, dynamic SSDs increase or decrease in duration following every successful or unsuccessful trial, respectively. This procedure yields an overall mean inhibition success rate of approximately 50%, suggesting the relative finishing times of a participant's go- and stop-processes are roughly the same, and consequently, a participant's SSRT may be estimated by simply subtracting SSD from MRT (i.e., MRT – SSD = SSRT).

Tri-Pathway Model of ADHD. Sonuga-Barke and colleagues' (2010) tri-pathway model of ADHD describes three pathways: temporal processing, inhibitory control, and delay aversion. Temporal processing involves duration discrimination (i.e., pressing a left button if the first tone presented was longer than the second tone presented and pressing a right button if the second tone presented was longer than the first tone presented), time anticipation (i.e., anticipating when a visual stimulus would return on a screen), and timing skills such as tapping at the same pace as an auditory stimulus. Inhibitory control is parsed into cognitive and behavioral inhibition. Cognitive inhibition refers to interference control and executive processes that limit extraneous information from gaining access to working memory (Miller & Cohen, 2001; Laurenson et al., 2015), and is commonly indexed by tasks such as the Modified Stroop Task. Consistent with Logan and Cowan's (1984) operational definition, the behavioral inhibition construct in Sonuga-Barke et al.'s (2010) model refers to processes associated withholding and/or stopping prepotent responses in the presence of prepotent stimuli (Castellanos et al., 2006; Alderson et al., 2007), and is indexed by metrics such as the SST (Logan & Cowan, 1984), Go/No-Go task (Iaboni et al., 1995), and CPT (Rapport et al., 1987).

The tri-pathway model (Sonuga-Barke et al., 2010) suggests that children with ADHD act impulsively due to both inhibitory deficits and a hypersensitivity to delays (i.e., difficulties in waiting for preferred outcomes and working while waiting for prolonged periods of time). To that end, a delay aversion in children with ADHD leads to task disengagement and presents phenotypically as hyperactivity and impulsivity. Children with ADHD may also present as inattentive due to their focus of attention on non-task related environmental cues rather than the task at hand, because the environmental cues decrease the perceived delay duration and/or allow them to ignore the delay. Notably, deficits in temporal processing, inhibitory control, and delay aversion in children with ADHD may lead to difficulties regulating thoughts and emotions, which in turn contribute to socially inappropriate actions (Sonuga-Barke, 2003). For example, children with ADHD who exhibit inhibitory deficits (Nigg, 2001; Willcutt et al., 2003) and difficulty with delayed gratification (Rodriguez et al., 1989) may demonstrate socially inappropriate behaviors such as not taking turns, interrupting, and acting aggressively.

Hierarchical-unified Model of ADHD. Barkley's (1997) hierarchical-unified model of ADHD incorporates elements of the tri-pathway model, such that impaired behavioral inhibition serves as the central deficit that underlies the disruption of other executive abilities and ultimately leads to the ADHD phenotype characterized by attention deficits, hyperactivity, and impulsivity. Specifically, the model predicts that impaired executive abilities, such as working memory (i.e., the ability to hold and manipulate information in one's mind), reconstitution (i.e., the examination of behavior), self-regulation of affect-motivation-arousal, self-control, and internalization of speech, are downstream of behavioral inhibition deficits.

Barkley's ADHD model provides several possible explanations for why children exhibit social functioning impairments. Decreased social competence and status may be explained by delays in moral reasoning, which is associated with the executive function of internalization of speech (Barkley, 1997). Likewise, impaired working memory may contribute to difficulties successfully applying social skills in high working memory demanding settings, while deficits of inhibition may yield disruptive, intrusive, and interrupting behaviors that are viewed unfavorably by peers and adults (Barkley, 1997; Nijmeijer et al., 2008). Moreover, poor self-regulation of affect-motivation-arousal and reconstitution that are characteristic of ADHD is associated with negative emotional reactivity in social situations and more difficulties in interpersonal interactions (Barkley, 1997). Inhibition centric models proposed by Barkley (1997) and Sonuga-Barke et al. (2010), however, have been challenged by findings from meta-analytic (Alderson et al., 2007; Lijffijt et al., 2005) and experimental studies (Alderson et al., 2008; Alderson et al., 2010) that suggest estimates of ADHD-related inhibitory deficits, as indexed by the stop-signal reaction time (SSRT) metric, appear to reflect impairments in control-focused attention rather than inhibition.

Working Memory Model of ADHD.

Working memory is an executive function that allows for the temporary storage, maintenance, and mental manipulation of phonological and visuospatial information needed to guide behavior and complete complex tasks, such as learning, comprehension, and planning (Baddeley, 2010). There are various models of working memory that differ predominantly with respect to the role of central executive processes, long-term memory, and the extent to which working memory processes are parsed into separate components of the overall system. Cowan's (2005) working memory model, for example, suggests that working memory acts as a temporary executor of long-term memory areas, such that controlled-focused attention places a spotlight on a portion of long-term memory that is brought into conscious awareness. Baddeley's (2007) multicomponent working memory model, in contrast, identifies anatomically and functionally distinct central executive, phonological loop, visuospatial sketchpad, and episodic buffer processes that are separate from long-term memory. Specifically, Baddeley's model describes a domain-general central executive that acts as an attentional controller involved in directing information to the phonological and visuospatial storage/rehearsal systems, dividing attention among concurrent tasks, and protecting temporarily stored information from internal or external distracting information (Baddeley, 2007; Engle et al., 1999). The phonological loop is the basis for speech perception and production, and provides a limited capacity temporary store and rehearsal of phonological/verbal-acoustic information. The visuospatial sketchpad serves as an analogous visuospatial system to the phonological loop, and therefore allows for temporary storage and rehearsal of visuospatial information (Baddeley, 2007). Finally, the episodic buffer acts as a limited capacity buffer/store that allows for temporary storage and maintenance of episodes/chunks of multimodal information and plays a role in linking working memory with long-term memory (Baddeley et al., 2011; Baddeley, 2012).

Rapport's et al.'s (2001) functional working memory model of ADHD incorporates Baddeley's (2007) more general working memory model and suggests that biological influences such as prenatal factors and genetics lead to individual differences in the function of dopaminergic-noradrenergic neurotransmission, or more broadly neurobiological systems. These biological influences in turn lead to working memory deficits, resulting in the cognitive and behavioral impairments seen in ADHD. Specifically, Rapport and colleague's model suggests the ADHD phenotype, characterized by DSM-V defined core symptoms of inattention, hyperactivity, and impulsivity, is downstream of deficits in working memory. Notably, the model is novel in its explanation of ADHD-related hyperactivity by suggesting increased motor activity exhibited by children and adults with ADHD serves a compensatory function to increase cortical arousal associated with working memory functioning when an environmental context places high demands on working memory. Likewise, ADHD-related inattention may present as stimulus-seeking behavior when children with ADHD experience trouble maintaining information in working memory, or a more basic impairment of controlled-focused attention associated with the central executive component of working memory (Alderson et al., 2007; Alderson et al., 2008; Alderson et al., 2010; Kofler et al., 2013; Lijffift et al., 2005; Raiker et al., 2012). Finally, the functional working memory model (Rapport et al., 2008) suggests that impulsive behavior exhibited by children with ADHD occurs due to limited working memory resources necessary to adequately weigh choice options (e.g., choice of immediate-small reinforcer over delayed-larger reinforcer; Patros et al., 2015), a compensatory strategy to respond before information decays from working memory (e.g., blurting out answers during class; Kofler et al., 2011), and/or failure to access previous-related experiences stored in long term memory so that they may be held in working memory during decision making (Fabio et al., 2020).

A growing body of literature provides strong evidence of reliable moderate to large working memory impairments in children with ADHD (Kasper et al., 2012). Moreover, findings from experimental studies indicate ADHD-related working memory impairments are causally related to hyperactivity (Alderson et al., 2012; Patros et al., 2017; Rapport et al., 2009; Rapport et al., 2008) and inattention (Kofler et al., 2010), and appear to underlie impulsivity (Patros et al., 2015) and lack of inhibitory control (Alderson et al., 2007; Alderson et al., 2010; Alderson et al., 2015; Tarle et al., 2019). Extant findings further suggest that secondary impairments of the disorder are significantly associated with working memory deficits. To that end, Rapport's functional working memory model suggests that working memory deficits lead to boredom, inattentiveness, low frustration tolerance, CNS arousal, and increased activity level, which in turn leads to impaired social functioning (Rapport et al., 2001). Excess demands on working memory may also contribute to fewer available resources needed to access social skills from long-term memory, and once accessed, to effectively evaluate and execute them from conscious awareness in working memory (Kofler et al., 2011). Evidence for this prediction is supported from studies of social skills training programs that indicate children with ADHD are able to learn pro-social skills and demonstrate knowledge of them post-treatment, but are unable to adequately draw upon the newly learned skills in real-world social settings (Abikoff, 2009; Mikami et al., 2014; Mikami et al., 2017). Finally, rapid decay of information from working memory is another hypothesized factor that contributes to social impairments in children with ADHD, as impulsive-interruptive behavior often increases in social setting when children with ADHD attempt to engage before information maintained in working memory is no longer available (Rapport et al., 2008).

Neurodevelopmental Model. Halperin and Schulz's (2006) neurodevelopment model of ADHD suggests that stable and indirect damage to the prefrontal cortex, or more specifically, the basil ganglia, midbrain dopamine system, hindbrain noradrenergic mechanisms, and/or cerebellum may promote the manifestation of ADHD. As the prefrontal cortex and related neural systems develop, they implement top-down executive control and moderate the severity of ADHD symptoms. To that end, ontologically late development of the prefrontal cortex and related neural systems may explain why ADHD symptoms sometimes diminish in adolescents and young adults (Shaw et al., 2006; Turgay et al., 2012), and why adults with impaired executive functioning are more likely to continue experiencing ADHD-related symptoms (Halperin et al., 2008; Nigg et al., 2005). Halperin and Schulz's (2006) model does not specifically explain ADHD-related social functioning impairments, but implies that executive functioning deficits associated with the prefrontal and frontal areas of the cortex may lead to social functioning deficits, such as difficulties with interrupting and regulating emotions and behaviors.

General Overview of Executive functions and ADHD

Many, if not all, models of ADHD described above incorporate executive functions, which involves top-down processing that allows for cognitive control of behavior (Graziano et al., 2013). Examples of executive functions include planning, set-shifting, attention, problem solving, temporary storage of information, and action regulation (Lee et al., 2013). The specific executive functioning tasks examined in this study involve self-control, behavioral inhibition, and working memory.

Self-control.

Self-control is broadly defined but most often indexed in ADHD research as a response style characterized by choice of large-delayed reinforcers over smaller-immediate reinforcers (Patros et al., 2016; Logue et al., 1988; Logue et al., 1990). For example, Mischel's (1974) classic delay-of-gratification paradigm offers young children one marshmallow immediately or multiple marshmallows if they wait some duration of time (Logue, 1988). More contemporary paradigms typically present two choice-reinforcement schedules across multiple trials with token economies (Patros et al., 2016) or hypothetical rewards (Patros et al., 2015; Solanto et al., 2001; Sonuga-Barke, 2003). Children that reliably choose delayed-larger rewards in lieu of small-immediate rewards are said to exhibit self-control because they are able to delay gratification and maximize their total density of reinforcement (Flora & Pavlik, 1992). In contrast, children who exhibit a response style characterized by choice of immediate-small rewards are described as being impulsive (Johansen et al., 2009).

Rapport et al. (1986) were the first to examine this construct in ADHD and found that children with ADHD chose immediate rewards more often than control children. A series of subsequent studies by Sonuga-Barke's research group aimed to determine specific factors that contribute to ADHD-related self-control deficits by systematically manipulating subject and task variables, such as participant age (Sonuga-Barke et al., 2003), pre-reinforcement delays (Sonuga-Barke et al., 1989), post-reinforcement delays (Sonuga-Barke et al., 1992), and reward modalities (Sonuga-Barke et al., 2016). Indeed, the reliability of ADHD-related self-control deficits across studies contributed to self-control garnering consideration in multiple contemporary models of ADHD. For example, the delay aversion task construct described in Sonuga-Barke et al.'s (2010) tri-pathway model is predominantly based on findings from studies of ADHD-related performance on self-control paradigms. Similarly, Barkley's (2007) unified model of ADHD describes self-regulation of affect-motivation-arousal and self-control as impaired executive functions that occur secondary to deficits of behavioral inhibition.

Recent meta-analytic findings provide compelling evidence of reliable moderate to large magnitude self-control deficits in children and adults with ADHD (Patros et al., 2015; Pauli-Pott & Becker, 2011). Findings from recent research, however, evince context dependent heterogeneity in ADHD-related self-control deficits (Patros et al., 2015; Schweizer & Sulzer-Azaroff, 1995), and suggest impaired self-control decision making processes may be downstream of working memory deficits (Patros et al., 2015).

Behavioral Inhibition.

Existing models of ADHD suggest that impaired behavioral inhibition, the ability to withhold or discontinue a prepotent response, serve as a central core feature (Barkley, 1997; Sonuga-Barke et al., 2010) or one of a number of executive function deficits associated with frontal and prefrontal cortical dysfunction (Halperin & Schulz, 2006; Halperin et al., 2008). Early studies of inhibitory processes in ADHD examined the construct with the Matching Familiar Figures Task (MFFT) and found that children with ADHD consistently make more errors and respond more quickly than typically developing children (Kagan et al., 1964; Campbell et al., 1971). The MFFT has fallen out of favor, however, due to questionable construct validity stemming from evidence of performance variability not related to inhibition, such as motivation (Kahneman, 1973) and search strategy (Ault et al., 1972). Moreover, the MFFT fails to align with Logan and Cowan's (1984) race model of inhibition that describes competing go and stop processes that determine the execution or inhibition of a prepotent behavioral response following presentation of a prepotent stimulus. In contrast, Schachar and colleagues' (1990) seminal study utilized the stop-signal paradigm that provides reaction time indices of both go and stop processes, consistent with Logan and Cowan's (1984) model, and concluded that children with ADHD have an inhibitory control deficit due to abnormally slow stop-signal reaction times (SSRT). The stop-signal task continues to be the premiere metric used to examine behavioral inhibition in children (Alderson et al., 2007; Lijffijt et al., 2005, Oosterlaan et al., 1998; Schachar et al., 1995), adolescents (Martel et al., 2007; Liotti et al., 2007) and adults with ADHD (Lijffijt et al., 2005; Bekker et al., 2005; Shen et al., 2014).

Findings from multiple experimental studies and meta-analytic reviews of behavioral inhibition in children with ADHD have been both reliable and contentious. Oosterlaan and colleagues' (1998) meta-analysis reported a significant, medium-magnitude between-group difference in mean reaction time to both go and stop stimuli (i.e., SSRT), indicating that children with ADHD exhibited slow go-responses and inhibitory deficits relative to typically developing children. Lijffijt et al.'s (2005) subsequent meta-analysis similarly found that children with ADHD were slower and more variable in their responses to both go- and stop-stimuli. However, Lijffijt and colleagues found that children with ADHD on average did not exhibit disproportionately slower SSRTs relative to their MRTs, suggesting SSRT between-group performance differences reflect processes of controlled-focused attention and decision making, rather than behavioral inhibition.

A meta-analytic review by Alderson et al. (2007) similarly reported that, at the aggregate level, children with ADHD exhibited significantly slower MRTs and SSRTs relatively to typically developing children. Notably, Alderson and colleagues also estimated between-group differences in children's SSD by algebraically solving for the SSD metric via the equation MRT – SSD = SSRT, and found that the groups' SSD estimates were not significantly different. Alderson and colleagues proposed that the non-significant group difference in SSD indicated that moderate effect size estimates for SSRT were attributable to basic attention and decision-making processes associated with completing the go-task component of the stop-signal task, rather than inhibition. Findings from a follow-up experimental study (Alderson et al., 2008) corroborated the conclusions of the previous meta-analytic reviews by indicating children with ADHD, relative to typically developing children, exhibited slower and more variable reaction times to go-stimuli, as well as slower stop-signal reaction times. Notably, the study was the first to directly examine between-group differences in SSD and found that the groups were not significantly different. Collectively, findings from these studies appear to suggest that between-group variance in the SSRT inhibition metric is predominantly attributable to between-group differences in MRT, and consequently undermine models that suggest behavioral inhibition impairments are a core deficit of ADHD.

Non-significant between-group SSD effects are not the only factor that raises questions about the construct validity of the stop-signal task as a metric of behavioral inhibition in ADHD research. For example, Alderson and colleagues (2010) examined the indirect effect of ADHD on stop-signal inhibition through working memory via bootstrapped mediation analyses, and found that ADHD-related working memory deficits impaired behavioral inhibition, as indicated by the SSRT metric. More recently, Alderson and colleagues (2015) used a dual-task paradigm to experimentally examine the relationship between working memory and behavioral inhibition deficits in children with ADHD. Specifically, children with ADHD and typically developing children were presented a working memory condition, stop-signal inhibition condition, and dual-task condition that placed concurrent demands on working memory and behavioral inhibition processes. In contrast to previous findings, compared to performance during the simple conditions, the working memory performance in both groups significantly decreased when concurrent stop-signal demands were presented during the dual-task condition. Even more, inhibitory performance was unaffected by concurrent working memory demands, suggesting that stop-signal task performance is upstream of working memory processes. Tarle et al. (2019) suggested that the unexpected findings of Alderson and colleagues' (2015) experimental study resulted from the use of n-back task metrics of working memory, rather than span tasks more frequently used in previous investigations. To that end, Tarle and colleagues hypothesized that the choice-reaction time component of the stop-signal task limits its construct validity as a pure measure of inhibition, given that choice-reaction time tasks place demands on working memory through controlled-focused attention, stimulus detection, stimulus categorization/discrimination, response selection, and responding/motor execution (Donders, 1969; Cowan, 1997; Huizenga et al., 2009; Oberauer, 2003). In contrast, go/no-go tasks require simple-reaction time responses to single stimuli, and consequently places fewer demands on working memory (i.e., detection, categorization, and responding). Indeed, compared to the stop-signal task paradigm, go/no-go tasks allow for response automaticity via continuous responding and generally produce less noisy data (Verbruggen & Logan, 2008; Gordon & Caramazza, 1982).

Finally, it is noted that evidence for the ability of inhibition to account for core ADHD symptoms has been underwhelming. For example, to the extent that inhibition is a limited resource that declines with continued use (Muraven & Baumeister, 2000; Muraven et al., 2006) and is involved in regulating motor activity (Barkley, 1997; Sonuga-Barke, 2003), varying inhibition demands via lab-based tasks that place differential demands on inhibitory processes would be expected to causally yield variability in motor activity. Further, children with ADHD would be expected to exhibit hyperactivity under conditions of relative high inhibition demands. A recent study, however, found that children with ADHD did not exhibit increased motor activity during high inhibition tasks, suggesting behavioral inhibition does not underlie ADHD-related hyperactivity (Alderson et al., 2012).

Working Memory.

ADHD-related working memory impairments have garnered considerable attention over the last two decades as commonly associated neurocognitive deficits (Kasper et al., 2012; Shaw et al., 2007; Dickstein et al., 2006; Barry et al., 2005; Rapport et al., 2008), candidate endophenotypes (Nigg et al., 2018; Hwang-Gu & Gau, 2015), moderators of ADHD severity (Halperin & Marks, 2019), and/or central core features that underlie the ADHD phenotype (Rapport et al., 2008). Extant meta-analytic studies of working memory functioning in ADHD have been relatively consistent in finding moderate to large magnitude ADHD-related impairments (Willcutt et al., 2005; Martinussen et al., 2005; Kasper et al., 2012), but vary with respect to conclusions about the centrality of working memory deficits to ADHD and the role of specific working memory component processes. For example, the first meta-analytic review of ADHD-related working memory functioning found evidence of moderate phonological working memory deficits ($d = .59$) and moderate to large visuospatial working memory deficits ($d = .75$; Willcutt et al., 2005). Willcutt and colleagues (2005) concluded, however, that working memory was not a central deficit of ADHD due to significant heterogeneity of findings across studies. Martinussen and colleagues' (2005) subsequent meta-analytic review grouped studies that required mental manipulation/re-ordering as verbal and visuospatial central executive, and studies that required simple storage/rehearsal processes as verbal and visuospatial storage. Overall, children with ADHD were associated with moderate verbal storage (ES = .47) and verbal central executive (ES =

.43) deficits, and large spatial storage (ES = .85) and spatial central executive (ES = 1.06) deficits (Martinussen et al., 2005). Inferences from the review about specific WM component processes involved in ADHD-related deficits are limited, however, given the authors' methodology implies central executive and storage/rehearsal WM processes may be observed as separate constructs across tasks. No individual task, however, may adequately parse WM components to provide pure metrics of central executive and storage/rehearsal processes. That is, both central executive and storage/rehearsal processes are involved in all WM tasks, and WM tasks differ with respect to relative demands on WM component processes. A more recent meta-analytic review examined the contribution of central executive demands and other participant and task characteristics on between-group effect sizes via a series of meta-regressions, and found that studies that placed relatively high demands on central executive processes, included fewer females, presented a greater numbers of experimental trials, and used recall tasks in lieu of recognition tasks were associated with larger between-group effect sizes (Kasper et al., 2012). Also notable from Kasper and colleagues' review was its examination of best-case estimation procedures. Specifically, solving the meta-regression equation with coefficient values associated with best-practice procedures predicts that 98% of children with ADHD will exhibit WM performance below the mean of TD children. This counters Wilcutt et al.'s (2005) conclusion that WM impairments are not central to ADHD, and suggests previous estimates of ADHD-related heterogeneity in WM performance are confounded by methodological variability.

Examinations of specific working memory components in experimental ADHD studies have yielded relatively equivocal findings. For example, Rapport et al. (2008)

used a latent variable approach to statistically parse and examine shared performance variability (i.e., a predicted score) between VS and PH WM tasks that was hypothesized to reflect the domain general central executive (CE), and residual variance hypothesized to reflect the independent visuospatial (VS) and phonological (PH) buffer/rehearsal loops. Collectively, findings indicated moderate magnitude PH and VS storage/rehearsal deficits, and an exceptionally large magnitude CE deficit. Notably, Gibson et al. (2009, 2018) have argued that Rapport et al.'s (2008) latent variable approach yielded inaccurate estimates of WM component processes since error variance is not retained in the predicted scores, which in turn leads to inflated PH and VS storage/rehearsal effect size estimates in comparison to the CE effect size. Gibson et al. (2018) alternatively estimated VS storage/rehearsal, PH storage/rehearsal, and CE latent variables via a bifactor modeling approach, and found that children with ADHD showed no significant deficits in VS storage/rehearsal processes, small-magnitude deficits in PH storage/rehearsal processes, and large-magnitude deficits in domain-general CE processes. Finally, recent studies have begun to examine the relatively new episodic buffer component of working memory and findings appear to suggest episodic buffer deficits in children with ADHD (Kofler et al., 2018; Alderson et al., 2021).

Finally, a growing body of literature provides compelling evidence that ADHD-related working memory deficits underline DSM-5 defined core deficits, such as hyperactivity (Rapport et al., 2009; Hudec et al., 2015), inattention (Kofler et al., 2010), and impulsivity (Patros et al., 2015). Working memory deficits also appear to underlie secondary symptoms of ADHD, such as academic underachievement (Martinussen &

Major, 2011), emotion dysregulation (Groves et al., 2020), and social deficits (Kofler et al., 2011).

Integration of Social Functioning and EF Research

Examinations of the relationship between ADHD-related social functioning and executive functions often examine an aggregate metric of executive functioning (e.g., combining working memory, behavioral inhibition, and other executive functions into one metric), and findings from such studies have been relatively equivocal. Biederman et al. (2006), for example, categorized participants into four groups (i.e., control group with no executive functioning deficits, control group with executive functioning deficits, individuals with ADHD, and individuals with ADHD and executive functioning deficits) and found that individuals with ADHD and deficits of executive functioning scored lower on the social and leisure subscale of the Social Adjustment Scale, compared to individuals with ADHD without executive functioning deficits. Holst and Thorell (2020) more recently compared a clinical control group to ADHD groups with and without executive function deficits, and found that adults with ADHD and executive function deficits reported significantly poorer quality social contacts with family members. Diamantopoulou and colleagues (2007), in contrast, found that higher aggregate mean parent and teacher ratings of ADHD symptoms and lower executive functions were associated with significantly lower Social Preference scores. However, executive functions were not a significant predictor of social functioning after statistically controlling for ADHD symptoms. Tamm et al. (2021) similarly found that executive functioning was not uniquely associated with parent or teacher social performance ratings after statistically controlling for ADHD symptoms and age. Finally, findings from mediation model studies that examined an aggregate metric of social functioning have also been mixed. Motamedi et al. (2015), for example, found that executive functioning deficits mediate the association between ADHD-related inattention and social withdrawal. In contrast, Huang-Pollock et al. (2009) used parent and teacher rating scales as well as the KSADS to determine whether a participant met criteria for ADHD, and found that executive functioning did not mediate the relationship between social skill deficits and ADHD status. A number of factors likely contribute to the heterogeneous findings across studies, such as between-study variability in diagnostic/grouping methods, the use of a clinical control group versus a typically developing control group, the specific metric of social functioning. The aggregation multiple executive functions into a single metric is also expected to contribute to between-study heterogeneity, given the range of possible executive functions and corresponding indices that might be included in aggregate measures.

Studies of the independent contribution of specific executive functions to ADHD-related social impairments have focused on WM processes. Kofler et al. (2011), for example, found that the relationship between deficient central executive working memory processes and impaired social functioning was significantly mediated by inattentive and hyperactive/impulsive symptoms of ADHD. In contrast, Fried et al. (2016) compared the social functioning of two groups of children with ADHD that varied with respect to WM deficits, and found there were no differences between the groups. Consideration of the studies' methodologies may provide insight about potential causes for the differences in findings. Specifically, Fried et al. (2016) compared children with ADHD to a heterogeneous group of typically developing children and children with psychopathology other than ADHD. This approach precludes inferences about the relationship between ADHD-related WM deficits and social functioning in general population, given Fried and colleagues' heterogeneous control group is not representative of an identifiable portion of the population. Moreover, Fried and colleagues utilized the Freedom from Distractibility Index from the WISC-R (derived from the Arithmetic, Digit Span, and Coding subtests) as their metric of WM. Although the Arithmetic subtest likely placed relatively high demands on working memory processes, findings from factor analytic (Egeland, 2015) and structural equation modeling (Engle, 2010) studies have provided strong evidence that simple span tasks such as the Digit Span subtest, place relatively few demands on the working component (i.e., central executive) of working memory.

To date, only a handful of studies have examined the unique contributions of specific executive functions (i.e., working memory, behavioral inhibition, planning, processing speed, reconstitution, and attention shifting) on social functioning in children and youth with ADHD. For example, Kofler et al. (2018) used a Bayesian framework to examine working memory, processing speed, and behavioral inhibition as predictors of ADHD-related social functioning impairments, and found that working memory and characteristic ADHD symptoms (inattention, hyperactivity, and impulsivity), but not behavioral inhibition, were significant predictors of social problems and social skills acquisition. Kofler and colleagues' findings contrast findings from previous studies that suggest inhibition deficits, rather than specific working memory deficits, significantly predict adolescent social functioning independent of group status (Miller & Hinshaw, 2010; Rinsky & Hinshaw, 2011), and highlight the role of methodological variability in estimating the complex relationship between these variables. For example, Miller and

Hinshaw (2010) and Rinsky and Hinshaw (2011) used the Conners' Continuous Performance Task (CPT; Conners, 1995) as a metric of inhibition, in lieu of the more common stop-signal paradigm (Alderson et al., 2007). There have been mixed findings on whether children with ADHD exhibit performance deficits on the CPT, with multiple studies not finding group differences (Epstein et al., 2003; McGee et al., 2000; Corkum & Siegel, 1993; Schachar et al., 1988; Werry et al., 1987). Moreover, the stop-signal task used by Kofler et al. (2018) is expected to place relatively greater demands on working memory processes, compared to the CPT (Alderson et al., 2007; Lijffift et al., 2005), given the stop-signal paradigm's choice-reaction time go task place requires controlled-focused attention, stimulus detection, stimulus categorization/discrimination, response selection, and responding/motor execution (Tarle et al., 2019). The go/no-go task (GNG; a modified CPT the presents a low density of non-response/stop trials), in contrast, places fewer demands on working memory (i.e., detection, categorization, and responding), allows for response automaticity via continuous responding, and generally produces less noisy data (Verbruggen & Logan, 2008; Gordon & Caramazza, 1982). To that end, it is possible that Kofler et al.'s (2018) multivariate analyses did not find inhibition to be a significant predictor due to multicollinearity associated with high working memory demands across both working memory and inhibition task predictor variables. Finally, it is noted that Miller and Hinshaw (2010) and Rinsky and Hinshaw (2011) examined working memory via the Rey Osterrieth Complex Figure Copy Condition Task (ROCF; Osterrieth, 1944) and WISC-III Digit Span subtest, respectively. The ROCF Copy Condition Task indexes multiple domains of executive functioning and does not provide separate subscales for each executive function, which in turn limits inferences about specific working memory processes. Although the digit span task used by Miller and Hinshaw (2010) and Rinsky and Hinshaw (2011) provides a more construct pure metric of working memory, findings from factor analytic (Egeland, 2015) and structural equation model (Engle, 2010) research suggest that simple span tasks place comparatively few demands on the central executive component of working memory. Notably, the central executive appears to be the component of working memory most impaired in children with ADHD, with large-magnitude impairments in the central executive and small to moderate impairments in visuospatial and phonological storage/rehearsal processes (Rapport et al., 2008; Kasper et al., 2012; Gibson et al., 2018).

Findings from mediation model studies have also been mixed. Bunford and colleagues (2015) found that hyperactivity/impulsivity symptoms of ADHD appear to mediate the relationship between inhibition and social functioning while inattentive symptoms of ADHD mediate the relationship between working memory and social functioning. Moreover, Hilton and colleagues (2017) found that ADHD-related attention problems mediate the relationship between working memory deficits and social problems. In contrast, Tseng and Gau (2013) found that working memory, but not inhibition, mediates the relationship between ADHD symptoms and social problems. Limitations of extant mediation model studies are similar to limitations previously described above. That is, multicollinearity between working memory and stop-signal inhibition metrics (Verbruggen & Logan, 2008; Gordon & Caramazza, 1982; Kofler et al., 2018), use of simple span working memory tasks (Engle, 2010; Egeland, 2015; Kofler et al., 2018), and use of an inhibition metric from the Stockings of Cambridge spatial planning test (Tseng and Gau, 2013), obscures inferences about the relative contributions of working memory and inhibitory processes to ADHD-related social problems.

Finally, it is noted that previous studies have focused on behavioral inhibition, working memory, and other executive functions in lieu of self-control. Self-control warrants consideration, however, due to previous findings that suggest children with ADHD exhibit impaired self-control/delayed gratification (Rodriguez et al., 1989) that in turn predicts socially inappropriate behaviors such as not taking turns, interrupting, and acting aggressively. Indeed, reliable findings from extant research suggest that self-control is significantly associated with interpersonal skills (Finkel & Campbell, 2001) and social acceptance among peers (Feldman et al., 1995; Ferrer & Krantz, 1987).

Table 1 Sample and Demographic Variables

	ADHD (n = 58)	TD (n = 63)		
	M (*SD*)	*M* (*SD*)	*t*	χ^2
Age in years	9.29 (1.52)	9.46 (1.38)	0.63	
FSIQ	99.07 (11.34)	110.07 (13.94)	4.63***	
Total family income	46,139.97 (24536.62)	49,377.14 (26932.72)	0.54	
Sex (F:M)	10:48	15:48	0.89	
Parent Education (%)				7.66
High school	8.33	6.90		
Partial college	27.08	12.07		
College degree	41.67	34.48		
Graduate degree	22.92	46.55		
Race/Ethnicity (%)				8.95
White	77.59	68.25		
Asian	0.00	12.70		
Hispanic	1.72	1.59		
Biracial	6.90	9.52		
Other	13.79	7.94		

ADHD attention-deficit/hyperactivity disorder; *FSIQ* Wechsler Full Scale Intelligence Quotient; *TD* typically developing

*** $p < .001$

Table 2 Zero-order Correlations Among Variables

Variable	1	2	3	4	5
1. Group (ADHD/TD)					
2. Social functioning (CBCL)	.48***				
3. Social functioning (TRF)	.50***	.52***			
4. Self control	-.24*	-.07	-.18		
5. Total commission error	.19*	.06	.07	-.06	
6. PH composite	-.41***	-.21*	-.36***	.44***	-.24*

Correlations with group are biserial correlations. *ADHD* attention-deficit/hyperactivity disorder; *CBCL* Child Behavior Checklist; *PH* phonological; *TD* typically developing; *TRF* Teacher Report Form

* $p < .05$, ** $p < .01$, *** $p < .001$

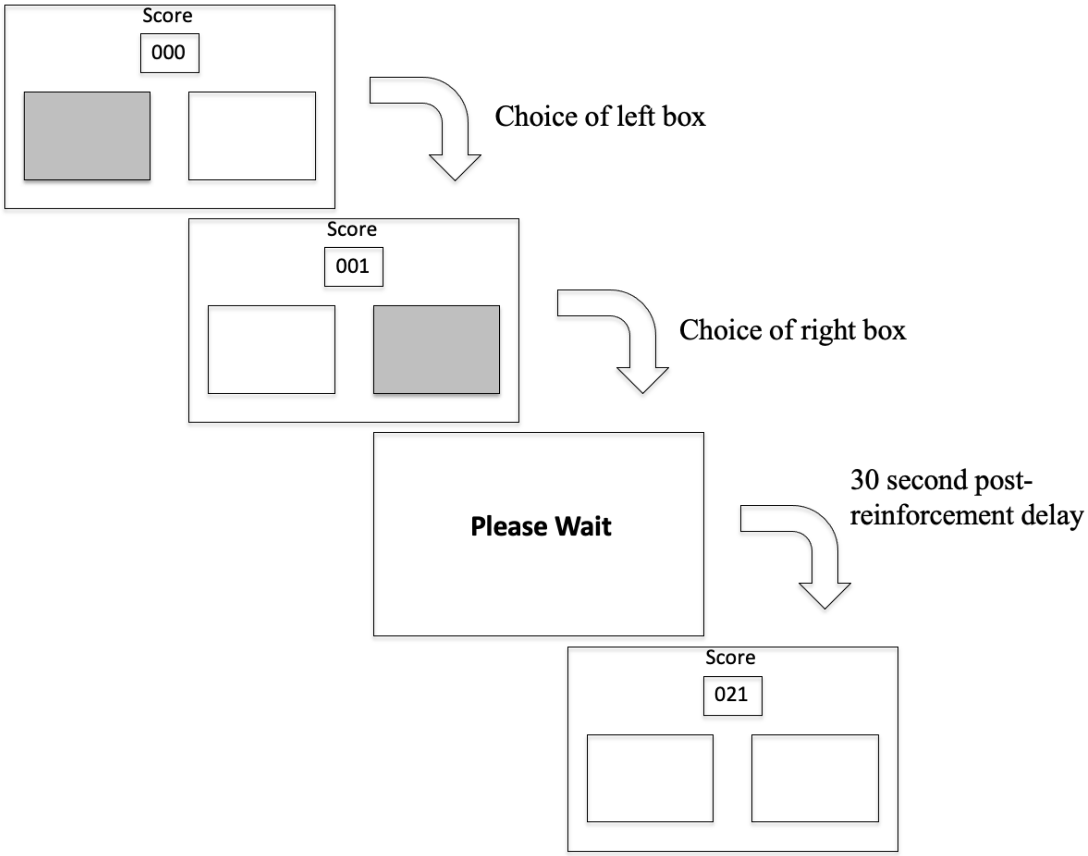
Table 3 Bootstrap Analyses of Indirect Effects

Grouping variable	Mediator variable	Dependent variable	Mean indirect effect (β)	*SE* of mean	95% CI for mean indirect effect
ADHD/TD	PH Composite	Social functioning (CBCL)	0.04	0.22	-0.36 to 0.50
ADHD/TD	PH Composite	Social functioning (TRF)	0.37	0.16	0.08 to 0.71*
ADHD/TD	Total commission error	Social functioning (CBCL)	-0.03	0.12	-0.30 to 0.21
ADHD/TD	Total commission error	Social functioning (TRF)	-0.03	0.09	-0.23 to 0.16
ADHD/TD	Self-control	Social functioning (CBCL)	-0.01	0.12	-0.34 to 0.20
ADHD/TD	Self-control	Social functioning (TRF)	-0.08	0.15	-0.25 to 0.38

ADHD attention-deficit/hyperactivity disorder; *CBCL* Child Behavior Checklist; *PH* phonological; *TD* typically developing; *TRF* Teacher Report Form

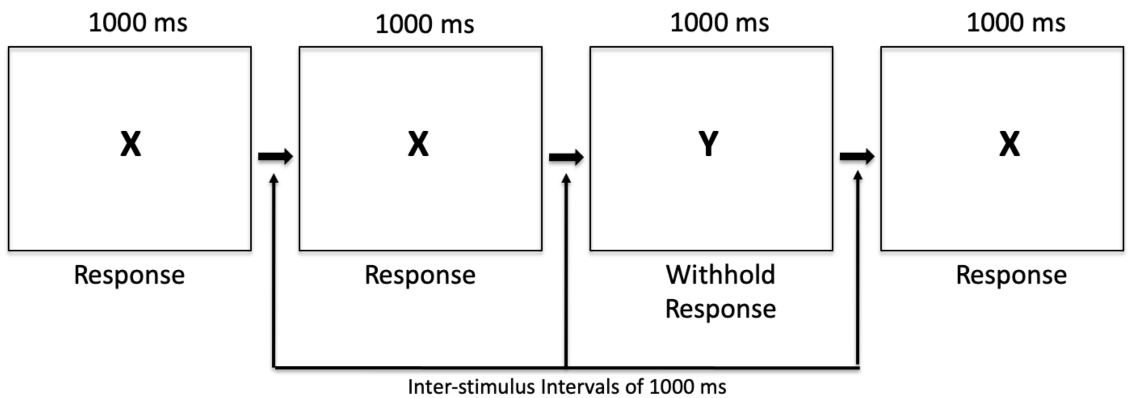
* $p < .05$

Figure 1 Self-control task



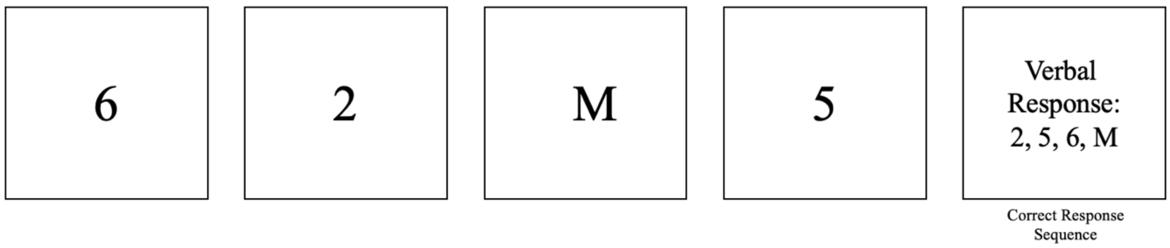
Note. Children are presented with two boxes that reflect different schedules of reinforcement. Clicking the left box results in an immediate increase of 1 point in the "score" box located at the top of the screen. Clicking the right box leads to the appearance of a "Please Wait" message for 30 seconds, after which 20 points are added to the score. Children are allowed to respond freely throughout the 600 seconds.

Figure 2 Go/no-go task



Note. Children are presented with either an X or Y on the screen. Children are instructed to click the mouse when they see a X and not click the mouse when they see a Y.

Figure 3 Phonological Task



Note. Children are presented with a letter and numbers in an auditory fashion. A stop light appears on the screen when the child is supposed to repeat the numbers and then letter sequentially. Once the child has recited what he/she remembers, he/she moves onto the next auditory presentation.

VITA

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