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Social Functioning in Children with ADHD: An Examination of Inhibition, Self-control, and Working Memory as Potential Mediators

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Abstract

Children with attention-deficit/hyperactivity disorder (ADHD) experience a host of social problems, in addition to significant impairments in behavioral inhibition, working memory, and self-control. Behavioral inhibition and working memory difficulties have been linked with social functioning deficits, but to date, most studies have examined the neurocognitive problems either in isolation or as an aggregate measure in relation to social problems, and none has considered the role of self-control. Thus, it remains unclear whether all of these executive functions are linked with social problems or if the link can be more parsimoniously explained by construct overlap. Fifty-eight children with ADHD and 63 typically developing (TD) children completed tests assessing self-control, behavioral inhibition, and working memory; parents and teachers rated children's social functioning. Examination of potential indirect effects with the bootstrapping procedure indicated that working memory mediated the relation between group membership (ADHD, TD) and child social functioning based on teacher but not parent ratings. Behavioral inhibition and self-control did not have direct relations with either parent- or teacher-rated social functioning. These findings point to important differences regarding how executive functioning difficulties manifest at school compared to home, as well as the specific executive function components that predict ADHD-related social difficulties.

Keywords

ADHD; inhibition; working memory; self-control; social

Attention-deficit/hyperactivity disorder (ADHD) is a neurodevelopmental disorder characterized by symptoms of hyperactivity, impulsivity, and/or deficits of attention (Sagar

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et al., 2017), and is estimated to be present in 3 to 7% of school-aged children (Lee et al., 2008; Selikowitz, 2009). Children with ADHD experience myriad social problems related to their noncompliant, disruptive, and aggressive behaviors that often result in peer rejection 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 neutral situations (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 & Gerdes, 2001; Hoza, 2007), tend to have fewer friends overall than typically developing children (Bagwell et al., 2001; Hoza et al., 2005), and are less likely than typically developing children 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 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-magnitude but significant deficits in ADHD-related social information processing (i.e., positive illusory bias and hostile attribution bias; Ros & Graziano, 2018).

Children with ADHD also exhibit significant impairments in a broad range of 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 the 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, and Motamedi et al. (2016) suggested that impaired executive functions mediated the relation between ADHD-related symptoms and social functioning. In contrast, Diamantopoulou et al. (2007) and Tamm et al. (2021) found that executive function impairments were 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 informant-reported 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 single source and/or a referral source and structured interview; Alderson et al., 2007; Patros et al., 2016), the use of a clinical control group versus a typically developing control group or the lack of a control group, and the metric used to assess 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 (Marsh et al., 2023). 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 relation 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 address construct overlap and parse the unique contributions of each toward social functioning in children and youth with ADHD (Kofler, Harmon, Aduen, et al., 2018; Miller & Hinshaw, 2010; Rinsky & Hinshaw, 2011). For example, Kofler, Harmon, Aduen, et al. (2018) examined working memory, processing speed, and behavioral inhibition as predictors of ADHD-related social functioning impairments, and found that working memory, but not behavioral inhibition, served as significant predictors of social problems and social skills acquisition, even when controlling for core ADHD symptoms (inattention, hyperactivity/impulsivity). Kofler, Harmon, Aduen and colleagues' (2018) findings are notable as they contrast findings from previous studies that suggest inhibitory control, rather than the short-term storage components of working memory, 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 relations among these constructs.

Findings from mediation model studies have also been mixed, both in terms of modeling approach and results. Interestingly, some studies modeled ADHD symptoms as mediators and executive functions as predictors (EF → ADHD symptoms → social problems), whereas other studies modeled executive functions as mediators and ADHD symptoms as predictors (ADHD → EFs → social problems). This difference appears to be based on the conceptual model the authors followed. For example, some authors viewed ADHD symptoms as an outcome of underlying executive function deficits (in which case EFs were modeled as the predictor and ADHD symptoms were the mediator), while other studies viewed executive functioning deficits as secondary components of ADHD (in which case ADHD symptoms were modeled as the predictor and EFs were the mediator). Specifically, Bunford and colleagues (2015) found that hyperactivity/impulsivity symptoms of ADHD appear to mediate the relation between inhibition and social functioning, whereas inattentive symptoms of ADHD mediate the relation between working memory and social functioning. Similarly, Hilton and colleagues (2017) found that ADHD-related attention problems mediate the relation between working memory deficits and social problems. In contrast, Tseng and Gau (2013) found that working memory, but not inhibition, mediated the relation between ADHD symptoms and social problems.

Limitations of previous studies include the use of complex inhibition tasks that may be confounded by the working memory demands required for successful task performance (Verbruggen & Logan, 2008; Gordon & Caramazza, 1982; Kofler, Harmon, Aduen, et al., 2018), use of simple span tasks (Engle, 2010; Egeland, 2015) that assess short-term storage/maintenance rather than the 'working' components of working memory (e.g., Fosco et al., 2020), and/or use of traditional neuropsychological tests that have been criticized as measures of gross neuropsychological functioning rather than specific executive functions (Snyder et al., 2015) – all of which 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* refers to the ability to delay gratification, is frequently defined as the opposite of reward-delay/choice impulsivity, and is typically defined in terms of choosing large-delayed reinforcers over smaller, more immediate reinforcers (Patros et al., 2016; Logue, 1988; Logue et al., 1990). 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). *Behavioral inhibition*, on the other hand, refers to rapid-response impulsivity and reflects the ability to withhold or discontinue a prepotent response (Barkley, 1997; Sonuga-Barke et al., 2010). Behavioral inhibition is often indexed by measures such as the stop signal paradigm (Logan et al., 1984) or go/no-go (GNG) task (Iaboni et al., 1995). Despite conceptual similarities, self-control/delay of gratification and behavioral inhibition/rapid-response impulsivity appear to reflect distinct subconstructs of the multidimensional impulsivity construct, tend to correlate modestly or nonsignificantly (Sonuga-Barke, 2003; Dalen et al., 2004), are measured using distinct metrics (how often children select the larger, delayed reward vs. response times, respectively), and differ in their convergent and ecological validity for children with ADHD, wherein behavioral inhibition tends to demonstrate equivocal prediction of impulsive behavior in the real world relative to stronger predictive/ecological validity of lab-based self-control tasks (for review, see Patros et al., 2016).

Self-control warrants consideration in studies of social functioning in ADHD due to meta-analytic findings that suggest children with ADHD exhibit moderate-magnitude deficits in self-control/delayed gratification relative to typically developing peers (Patros et al., 2016), and reliable findings that suggest self-control is significantly associated with interpersonal skills (Finkel & Campbell, 2001) and social acceptance among peers (Feldman et al., 1995; Ferrer & Krantz, 1987). Thus, the study aims to explore the relative contributions of self-control, behavioral inhibition, and working memory to ADHD-related social problems. Notably, the present study adds to the current body of literature due to its use of a GNG inhibition test and working memory tasks with high central executive demands. Use of the GNG (simple inhibition) task is expected to reduce construct overlap with working memory relative to the complex inhibition tasks used in most prior work (Tarle et al., 2019; 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., 2012; Alderson et al., 2015), and is therefore expected to provide a more valid metric of ADHD-related working memory impairments relative to the simple span tasks used in most previous studies (Kasper et al., 2012). 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

Working memory, behavioral inhibition, and self-control were all expected to significantly mediate the relations between ADHD diagnostic status (group membership) and both parent- and teacher-rated social problems when examined separately. These hypotheses were based on previous findings and theoretical models implicating executive functions as functional if not causal mechanisms that underlie, in part, behavioral and functional impairments in ADHD including social problems (Bunford et al., 2015; Hilton et al., 2017; Kofler, Harmon, Aduen, et al., 2018). In contrast, when modeled together (i.e., with all three executive functions included in a single mediation model), working memory was predicted to be the only significant mediator of the indirect effect of group membership on parent and 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).

Method

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 mass emails to local/university listservs. Fifty-eight (17.2% female; 22.4% ADHD Inattentive Presentation, 77.6% ADHD Combined Presentation) 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 (Table 1). 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.

Diagnostic Evaluation and Group Assignment

As detailed below, 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 the Diagnostic and Statistical Manual of Mental Disorders, 5th Edition (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. If a child was prescribed stimulant medication previously, a parent was instructed to discontinue medication at least 24 hours prior to each research session ($n = 12$).

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 K-SADS-PL (Kaufman et al., 1997), a semi-structured clinical interview 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).

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. The Social Problems scale assesses overall difficulties with social functioning (e.g., doesn't get along well with other kids, gets teased a lot). 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 delay of gratification/choice-impulsivity task (see Patros et al., 2015) and was programmed in Microsoft Visual Basic (Saradhara, 1991) software. Two 3.81 × 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 each 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 number 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 10 minutes and the total points children earned served as the dependent variable of the task, with more impulsive responding being associated with fewer points. Of note, the self-control measure had a smaller sample size compared to the other executive function metrics (n = 77–79 vs. n = 118–121 for all other variables) because the task was added later to the lab battery. The self-control task is shown in Figure 1.

Go/No-Go (GNG) Task—The GNG task described in Tarle et al. (2019) was used in this study as a metric of behavioral inhibition as it is a simple reaction time task that has fewer demands on working memory relative to more complex inhibition tasks (e.g., Verbruggen & Logan, 2008). 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 of 32 trials 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). Total commission errors (incorrectly responding to a no-go stimuli) served as the metric for response inhibition. Higher scores indicate worse response inhibition abilities. Figure 2 provides a visual schematic of the GNG task.

Phonological 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 counterbalanced 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 and testing days. 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). Stimuli correct per trial, averaged across the four stimulus set sizes, was the dependent variable, with higher scores indicating better working memory abilities. The working memory test is shown in Figure 3.

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 three hours. 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, 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 of the three EFs, separately for parent and teacher ratings of children's social functioning. Finally, multiple mediation models 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 unique predictors of variability in ADHD-related social functioning difficulties.

Power Analysis

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.

Results

Preliminary Analyses

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 of the whole sample (i.e., two values replaced in the Phonological Set Size Three variable, three values replaced in the Teacher Report Form variable, 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[1] attained by parents were used as proxies for socioeconomic status (SES; Bradley & Corwyn, 2002).

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[2], $t(72) = .54$, $p = .59$. Parents of children in the ADHD group attained lower average levels of education[3] compared to parents of children in the TD group[4], χ^2 (3) = 7.66, $p = .05$. 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). Sample and demographic data are shown in Table 1.

Intercorrelations—Table 2 displays intercorrelations among group membership (TD = 0, ADHD = 1), executive functions (i.e., working memory, behavioral inhibition, and self-control), and social functioning. ADHD status was significantly correlated with lower phonological working memory ($r = -.41$, $p < .001$), lower response inhibition ($r = .19$, $p = .04$), and lower self-control abilities ($r = -.24$, $p = .04$), as well as lower parent ($r = .48$, $p < .001$) and teacher ($r = .50$, $p < .001$) ratings of child social functioning. Better-developed phonological working memory was also associated with better self-control ($r = .44$, $p < .001$) and better response inhibition ($r = -.24$, $p = .01$). In contrast, response inhibition and self-control were not significantly correlated with each other ($r = -.06$, $p = .59$) or with parent or teacher reported social functioning ($r = .06$-$.07$; $p > .50$). Parents and teachers showed the expected moderate level of agreement in their ratings of child social functioning ($r = .52$, $p < .001$).

Bootstrapped Mediation Analyses—Examination of potential indirect effects with the bootstrapping procedure indicated that the relation between ADHD status and teacher ratings of child social functioning was significantly mediated by phonological working memory ($M_ß = 0.37$, $S.E. = 0.16$, 95% CI = 0.08 to 0.71). Phonological working memory, however, did not explain a significant proportion of the ADHD group's parent-rated social functioning deficits ($M_ß = 0.04$, $S.E. = 0.22$, 95% CI = −0.36 to 0.50). No other indirect effects were significant: Response inhibition did not explain a significant proportion of the ADHD group's parent-rated ($M_ß = -0.03$, $S.E. = 0.12$, 95% CI = −0.30 to 0.21) or teacher-rated social functioning deficits ($M_ß = -0.02$, $S.E. = 0.09$, 95% CI = −0.23 to 0.16). Similarly, self-control abilities did not explain a significant proportion of the ADHD group's parent-rated ($M_ß = -0.09$, $S.E. = 0.18$, 95% CI = −0.44 to 0.30) or teacher-rated social functioning deficits ($M_ß = 0.09$, $S.E. = 0.14$, 95% CI = −0.13 to 0.45). Standardized beta weights (interpreted as Cohen's d effect sizes because the predictor

[1]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).
[2]Total parent income data for 38 children were missing.
[3]In the case that data were provided for both mother and father, data from the parent with the highest level of education was used.
[4]Level of education data for 1 child was missing.

variable is dichotomous), 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 based on our hypothesis that all three neurocognitive constructs would predict ADHD-related social functioning (i.e., mediate the relation between ADHD status and social functioning), they were not conducted since only working memory was a significant mediator when examined alone as described above.

Discussion

The current study examined self-control, behavioral inhibition, and working memory as potential mediators of the relation between ADHD group membership and social functioning. Notably, this was the first study to examine the potential mediating role of self-control deficits in ADHD-related social problems. 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, children with ADHD exhibited lower levels of parent- and teacher-reported social functioning, self-control, behavioral inhibition, and working memory tasks than typically developing children. This pattern of results is generally consistent with previous literature (e.g., Alderson et al., 2010). Specifically, our finding that lower working memory abilities were associated with lower self-control scores is consistent with previous research (Patros et al., 2017; Rapport et al., 2009; Schweitzer & Sulzer-Azaroff, 1995). Similarly, our finding that better-developed working memory was associated with better behavioral inhibition is in line with the literature (Sonuga-Barke, 2002; Brocki et al., 2008; Alderson et al., 2010). Moreover, parent and teacher ratings of social functioning were positively correlated with each other as found in previous studies (Dekker, 2003). Both parent and teacher ratings of social functioning were associated with working memory, such that greater social problems were associated with lower working memory abilities, which was also consistent with previous literature (Kofler et al., 2011; Kofler, Harmon, Aduen, et al. 2018; Abikoff, 2009; Mikami et al., 2014; Mikami et al., 2017).

Contrary to expectations based on 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 neither predicted parent or teacher ratings of social functioning (Barkley, 1997; Nijmeijer et al., 2008; Sonuga-Barke, 2003; Sonuga-Barke et al., 2010). The lack of the relation between behavioral inhibition and parent and teacher ratings of social functioning is consistent with more recent findings (Kofler, Harmon, Aduen, et al., 2018; Tseng & Gau, 2013; cf. Miller & Hinshaw, 2010; Rinsky & Hinshaw, 2011), and extends those findings via the use of a simple inhibition task that was expected to reduce construct bleed given the task's lower working memory demands relative to the complex inhibition tasks used in most previous studies (Verbruggen & Logan, 2008; Gordon & Caramazza, 1982). Similarly, despite conceptual similarities, self-control/delay of gratification and behavioral inhibition/rapid-response impulsivity appear to reflect distinct subconstructs of the multidimensional impulsivity construct, and as such our finding that they were not significantly interrelated was generally consistent with prior work reporting that they correlate modestly or nonsignificantly (Sonuga-Barke, 2003; Dalen et al., 2004).

Mediation analyses were conducted to examine the potential indirect effect of group, through each executive function, on parent and 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 explain a significant proportion of the ADHD group's parent-rated social functioning deficits. These findings are consistent with recent findings of working memory effects on teacher-rated social functioning (Kofler et al., 2011; Kofler, Harmon, Aduen, et al., 2018). However, those previous studies also found support for working memory effects on parent-rated social functioning, which the current study did not. A potential explanation for this discrepancy may be because Kofler, Harmon, Aduen, and colleagues (2018) examined executive functions and ADHD symptoms as predictors of social problems, whereas the present study tested the extent to which executive functions explained the differences in social functioning between ADHD and TD children.

Alternatively, closer inspection of the Kofler, Harmon, Aduen, et al. (2018) data indicates that visuospatial working memory predicted both parent- and teacher-reported social functioning, whereas phonological working memory predicted only teacher-reported social functioning. Thus, the findings appear generally consistent with the current results given our use of a phonological working memory test, and suggest the need for future studies that fractionate the working memory system into its subcomponent parts (e.g., Kofler et al., 2020) to determine which aspect(s) of working memory impact social functioning for these children. Taken together, the current and previous study's findings highlight that working memory is a limited resource, and in an academic environment, where resources are being used for learning, fewer resources may be 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 children engage in at home compared to at school. For example, when one is at home, there is potentially less opportunity for peer 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 finding that behavioral inhibition did not explain a significant proportion of the ADHD group's parent-rated or teacher-rated social functioning deficits is consistent with more recent findings in the literature. For example, Kofler, Harmon, Aduen, 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. The present study used an inhibition metric (i.e., GNG task) that reduced construct overlap with the working memory task and examined the independent contribution of inhibition and working memory

(Tarle et al., 2019). 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 explain a significant proportion of the ADHD group's parent-rated or teacher-rated social functioning deficits. This may have occurred because self-control deficits appear to be downstream of working memory deficits as found in Patros and colleagues' (2015) study. In this conceptualization, self-control and social functioning may reflect independent outcomes of underlying working memory abilities, rather than self-control directly impacting social interactions independent of working memory (Patros et al., 2015; Alderson et al., 2010). This is a notable finding since the current study was the first to examine the potential mediating role of self-control deficits on the social difficulties exhibited by children with ADHD.

Strengths and Limitations

The current study had several strengths, including thorough clinical evaluations to obtain children's diagnoses and utilization of clear methodology (i.e., working memory task with high central executive demands), allowing for bolstering of the ADHD-related findings as well as clarification regarding the inconsistencies in measuring working memory in previous ADHD studies. At the same time, the following limitations should be considered when interpreting results. The study was powered to detect medium effects, so it is possible that behavioral inhibition and/or self-control may explain a small proportion of social problems in ADHD that may not have been detectable in the current study. Also, while the CBCL/TRF Social Problems narrow band scales have good reliability and validity characteristics, it is important to examine more specific social skills and measures (e.g., Social Skills Improvement System) in future studies to see if other measures map onto the CBCL/TRF Social Problems narrow band scales and give a larger picture of social functioning difficulties. Relatedly, despite concerns regarding the construct validity (Snyder et al., 2015) and ecological validity (Barkley, 2019) of traditional neuropsychological tests of 'executive function', modern performance-based executive function tests adapted from the cognitive literature – including those used in the current study – have shown more robust evidence for predicting important, ecologically valid behavioral and functional outcomes and appear to be superior to informant-rated 'executive function' scales in this regard (e.g., Kofler, Irwin, Soto et al., 2018; Tarle et al., 2017; Soto et al., 2020; Snyder et al., 2015; Patros et al., 2015). 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 more female participants, would help to examine if the results generalize to the broader population of children.

Clinical and Research Implications

Overall, the present study indicated that working memory is an important factor in the social difficulties that children with ADHD experience at school. In contrast, behavioral inhibition and self-control were generally unrelated to social functioning, both in terms of a lack of significant zero-order correlations and their inability to explain ADHD-related social difficulties in the mediation models. The current study adds important findings to the literature as it used tests that allowed for the roles of the different executive functions to be parsed apart (e.g., the use of a simple inhibition task with less construct overlap with working memory, and a working memory task with a high central executive demands). Moreover, this study was the first to examine the role of self-control in ADHD-related social functioning deficits. Future directions include examining other components of working memory besides phonological working memory (e.g., visuospatial working memory, the episodic buffer) to determine which subcomponent(s) of the working memory system account for the relations detected herein, 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. Finally, we speculate that this line of work may help explain the relative inefficacy of traditional social skills training interventions for children with ADHD (e.g., de Boo & Prins, 2007) particularly given emerging evidence that social problems in ADHD may reflect a performance problem rather than a knowledge problem (i.e., knowing what to do but having difficulty effectively implementing known skills in the moment; e.g., Aduen et al., 2018), which in turn is impacted at least in part by interfering factors including working memory difficulties (e.g., Kofler, Harmon et al., 2018). As this line of work moves from basic to applied/intervention research, it will be important to consider working memory difficulties when designing and/or modifying accommodations and treatments for social difficulties in children with ADHD.

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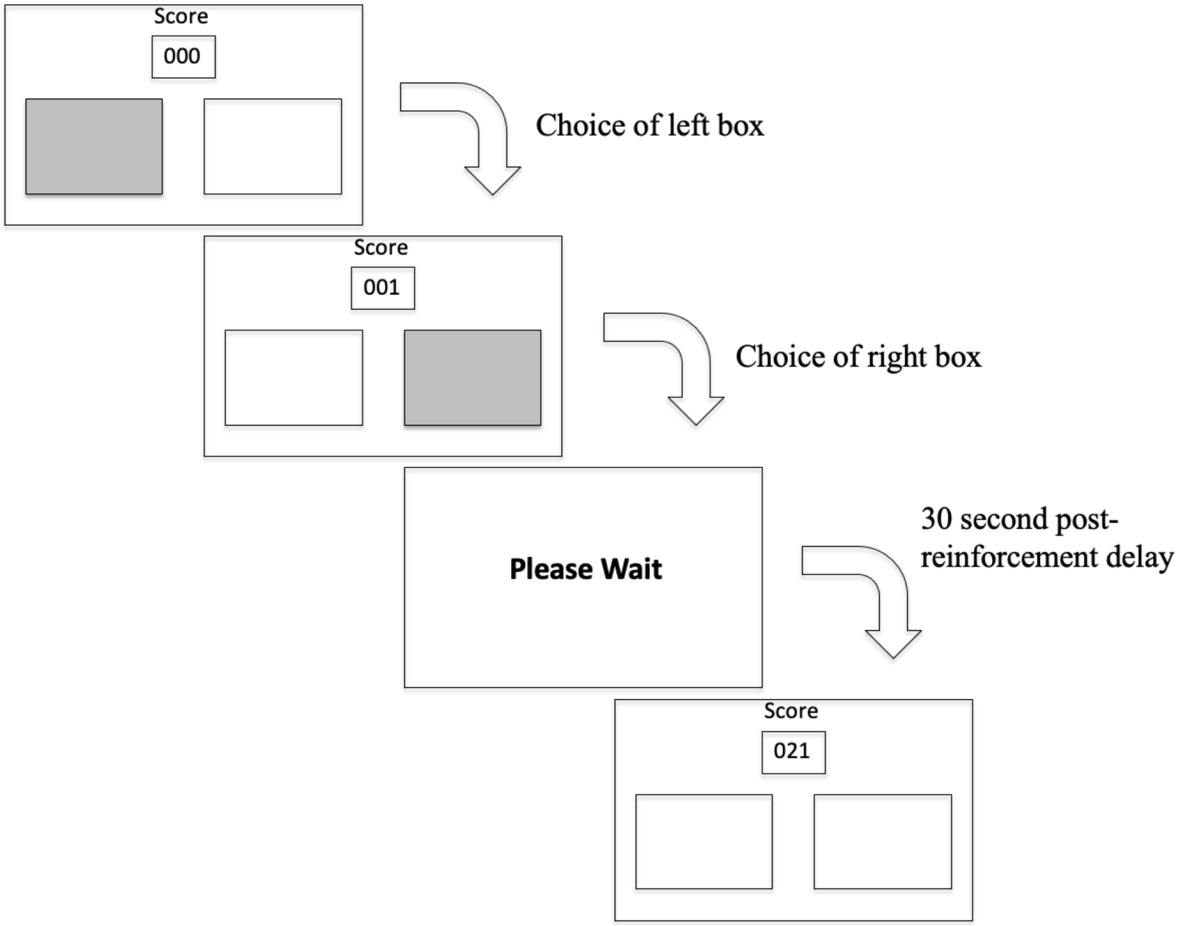

Figure 1. Self-control task

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.

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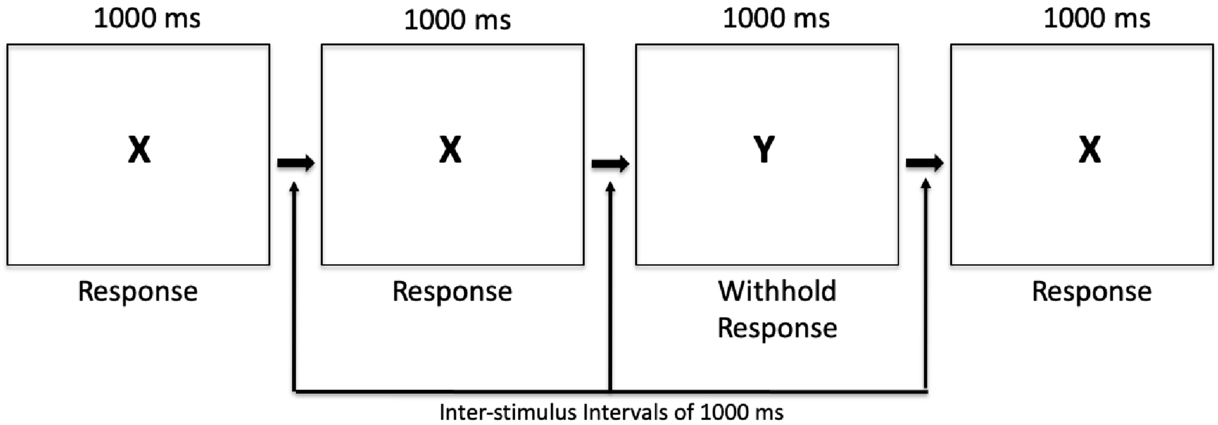

Figure 2. Go/no-go task

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.

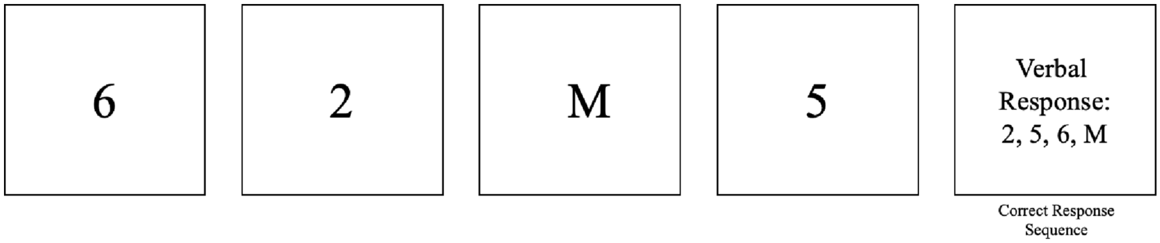

Figure 3. Phonological Task

Note. Children are presented with a letter and numbers in an auditory fashion. A green traffic 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.

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		
Task performance				
Working memory	2.26 (.92)	3.06 (.88)		
Behavioral inhibition	5.48 (3.65)	4.24 (2.92)		
Self-control	343.50 (30.62)	356.37 (22.88)		
Social functioning				
Parent report	4.88 (3.30)	1.94 (2.11)		
Teacher report	3.04 (2.96)	.51 (1.18)		

ADHD attention-deficit/hyperactivity disorder; *FSIQ* Wechsler Full Scale Intelligence Quotient; *TD* typically developing; Working memory = stimuli correct per trial (higher scores = better working memory); Behavioral inhibition = commission errors (lower scores = better inhibition); Self-control = points (higher points = better self-control/less choice-impulsive responding); Social functioning = T-scores (higher scores = more social difficulties).

* $p = .05$

*** $p < .001$

Table 2

Zero-order Correlations Among Variables

Variable	1	2	3	4	5	6
1. Group (TD = 0/ADHD = 1)						
2. Social functioning (CBCL)	.48***					
3. Social functioning (TRF)	.50***	.52***				
4. Self control	−.24*	−.07	−.18			
5. Response inhibition	.19*	.06	.07	−.06		
6. Phonological working memory	−.41***	−.21*	−.36***	.44***	−.24*	

Correlations with group are biserial correlations. *N*=118–121 for all correlations except those with the self-control task that was added to our test battery partway through data collection (*n*=77–79). *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

* $p < .05$