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Child Psychiatry & Human Development

ISSN 0009-398X

Child Psychiatry Hum Dev
DOI 10.1007/s10578-019-00915-3

Springer

Child Psychiatry & Human Development
https://doi.org/10.1007/s10578-019-00915-3

ORIGINAL ARTICLE

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Increased Working Memory Load in a Dual-Task Design Impairs Nonverbal Social Encoding in Children with High and Low Attention-Deficit/Hyperactivity Disorder Symptoms

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Abstract

Children with attention-deficit/hyperactivity disorder (ADHD) are known to have difficulty with peer relations, though the mechanisms by which these children struggle with interpersonal relationships are not well known. The current study examined the relation between working memory (WM) and the encoding of nonverbal social cues using a dual-task paradigm tested in children with High and Low ADHD symptoms. A total of 40 children were recruited (20 High ADHD; 20 Low ADHD) and completed computerized tasks of social encoding and WM in both single- and dual-task conditions. A series of repeated measures mixed-model ANOVAs revealed that both children with High ADHD and Low ADHD performed significantly worse during the dual-task condition compared to the single task conditions. Also, children with High ADHD had significantly lower performance than Low ADHD children on task-based social encoding and WM. This study supports the role of WM in nonverbal social encoding in children.

Keywords ADHD · Social encoding · Dual-task methodology · Social problems

Introduction

Close friendships with others are crucial for physical and mental well-being [1, 2], acting as a protective factor against a variety of negative outcomes [3–5]. In children, social difficulties and friendship problems have been associated with poor academic outcomes [6], behavioral difficulties [7], peer victimization [5], and loneliness [8]. In adults, a lack of close social relationships is a strong predictor of poor mental health and mortality [1]. Given social deficits' clear associations with a range of outcomes, new research is needed on specific mechanisms that perpetuate difficulties in relationships. One construct that has shown promise as a contributor to the quality of social interactions is executive function (EF).

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Executive Function and Social Functioning

EF has been defined historically as the functions of the prefrontal lobes that are involved in self-regulatory behavior, such as inhibition (inhibiting automatic responses), working memory (holding and manipulating new information relevant to the task at hand), and set shifting (switching attention back and forth between tasks) [9, 10]. Some theories of EF have postulated that this self-regulatory system may actually serve as the neurological basis behind social ability in humans [11–13]. While the literature base *directly* connecting EF to social functioning is still relatively scarce, there have been important advances in our understanding of this potential connection in recent years.

Studies in children have shown connections between parent and teacher reports of social impairment and deficits in task-based EF measures [14, 15]. Furthermore, in studies of individuals with ADHD, a disorder characterized by pronounced deficits in EF, the relationship between EF and social problems is mediated by ADHD symptoms [14, 16]. In addition, there is also evidence that the contributions of EF to social problems are independent of an ADHD diagnosis [17, 18].

Published online: 29 July 2019

EF, ADHD, and Social Functioning

While there is empirical support for the EF system's involvement in social functioning, further research must clarify what is likely a complex and nuanced relationship. Although comprehensive theories of EF apply to neuropsychological functioning across individuals with and without psychological disorders, it may be especially fruitful to study this relationship in children diagnosed with ADHD or those with elevated ADHD symptoms. As stated earlier, ADHD is characterized by deficits in self-regulation and specific areas of EF, as well as pronounced social problems [19, 20]. Social problems have been found to be among the most impairing deficits in ADHD [21] and EF deficits as well as the behavioral manifestations of ADHD have been shown to contribute to poor social outcomes [22–24]. As such, if a relationship between EF and any aspects of social functioning exists, this group presents as a prime target for early investigation of the connection between these constructs.

Research on relationships in ADHD suggests that between 52 and 82% of children with ADHD possess significant social problems [25–27]. Children with ADHD are rated as less popular and competent than peers [28], are quickly rejected by peers [29], are more likely to experience peer neglect, be bullied, or engage in bullying [26], and have fewer friends than peers [30]. Although children with ADHD do not typically report social problems, reports by parents, teachers, and peers consistently indicate relational problems [31].

Of the cognitive deficits found in children with ADHD, one the most widely studied is working memory (WM) [32]. In a recent meta-analysis, WM scores were found to differ between participants with and without ADHD by a greater magnitude than any other analyzed factor [20]. WM is consistently impaired in those with ADHD compared to controls even when accounting for comorbidity and general intelligence [33]. WM impairment has also been associated with poor social functioning in both children [14, 18] and adults [34].

Recent studies have examined potential mechanisms driving this relationship in ADHD and neurotypical populations. Kofler et al. [14] found that the behavioral symptoms of ADHD (i.e., hyperactivity/impulsivity and inattention) mediated the relationship between WM deficits and social problems in a group of young boys with ADHD. Bunford et al. [35] similarly observed that ADHD symptoms mediated the relationship between EF and social problems, with inattention mediating the relation between WM and social problems and hyperactivity/impulsivity mediating the relation between inhibition and social problems. In an investigation of the specific social problems associated with WM deficits, McQuade et al. [18] found that behavioral deficits (i.e., conflict resolution and physical aggression) mediated the relationship between WM and peer rejection and broad social competence, further supporting the notion that the behavioral manifestation of EF deficits leads to poor social functioning in children [14, 15]. Collectively, these studies suggest that poor WM ability leads to attentional and behavioral difficulties, which, in part, drives social functioning problems [14, 15, 35].

Social Encoding and ADHD

WM may thus play a significant role in successful social interaction, but investigations to date have relied on correlational methodologies to test this hypothesis. In studying EF and social functioning, it is important to note the exceedingly complex nature of both constructs. There is currently no consensus definition on EF, and it has sometimes been conceptualized as encompassing more than 30 different skills [11]. Models of social functioning also tend to be overwhelmingly intricate. In the Social Information-Processing (SIP) model of human interaction, there are at least six well-defined steps occurring in any social interaction: encoding of cues, interpretation of cues, clarification of goals, response access or construction, response decision, and behavioral enactment [36]. To make progress in understanding exactly how specific EFs impact the broad outcome of social functioning, we must also examine these skills in relation to specific components of well-established theories of social functioning. A logical first step is to examine social information-processing in a systematic fashion, beginning with the encoding of social cues.

Investigations of social encoding in relation to EF and ADHD have found that individuals with ADHD tend to encode fewer social cues than comparison children when presented with vignettes [37, 38]. Further, analyses of the errors in encoding show that these tend to be nonsystematic [37, 39, 40], which may indicate that inattention is the issue rather than biased attending [41]. This fits well with aforementioned findings that the relationship between WM and social problems is mediated by attention problems [14, 15, 35], logically supporting connections among WM, inattention, social encoding, and social impairment. Children with ADHD also have more trouble integrating and organizing social cues and are more likely to interpret social situations using the most recent contextual information [42], which may be a problem in either the encoding step of SIP or in the process of moving from encoding to interpretation.

Dual-Task Methodology

Although these studies advance understanding of how EF and social functioning are related, they are nevertheless correlational in nature, making causal interpretations impossible. Research must investigate the association by targeting specific EF skills and SIP components according to hypotheses informed by theory and past research. In order to begin establishing a causal connection, an experimental design approach is necessary. One promising experimental approach is dual-task methodology [43]. Having individuals engage in two tasks simultaneously while measuring performance in both allows for more direct measurement of utilized cognitive abilities than simple correlational methods, because tasks that rely on the same mental resources should interfere with each other when performed in synchrony [43].

Studies using the dual-task method of assessment have found support for the role of WM in the encoding of social cues and emotions; however, it appears the nature of the encoding task plays an important role in the outcome [43–45]. There is relative agreement among researchers that daily social judgments rely on both automatic processes requiring little effortful direction of attention and more cognitively taxing processes requiring both attention and working memory resources [43, 46]. In light of this, the degree to which a study's social encoding task taps these automatic versus effortful processes will influence the results. Despite possible limitations, there is a great deal of evidence from dual task studies [43, 45, 47] and brain lesion research that implicates similar brain networks in both social encoding and WM [48–50].

For example, Phillips and colleagues [43] found that WM resources were significantly more taxed and social encoding more impaired in a dual task employing the Profile of Nonverbal Sensitivity (PONS) [51] compared to a dual task using the Interpersonal Perception Task (IPT) [52]. The authors suggest the shorter time frame of clips used in the PONS (2 s) may tax WM more than the IPT, whose longer timeframe (30 s) may allow for other cognitive systems to aid in processing the information. Also, Gilbert and colleagues [47] found that executive load (i.e., remembering topics from previous conversations during current conversation) affects one's ability to accurately and effectively encode and interpret situational and dispositional cues in others, which again may indicate interference in either the encoding stage or organization of encoded information for interpretation.

The Present Study

The aim of the present study was to examine the relationship between working memory (WM) and nonverbal social encoding using a controlled experimental design in groups of children exhibiting either high or low ADHD symptoms (see "Participants"). As outlined above, WM is the EF skill that has been most consistently linked to difficulties in social functioning broadly as well as social encoding specifically; however, to date, there have been few controlled experimental manipulations of WM that allow for causal inferences through the establishment of temporal precedence in the relationship between WM load and social encoding.

Children with high and low ADHD symptoms completed a battery of tasks using a dual-task paradigm to examine the effect of taxing WM on children's ability to encode nonverbal social information. There were two main hypotheses and two secondary analyses. First, compared to children with low ADHD symptoms, children with high ADHD symptoms were expected to show greater deficits in measures of executive functioning and social problems as well as overall social encoding performance. Second, we expected to find a significant reduction in social encoding across both high and low ADHD symptom groups when comparing performance in dual-task versus single-task phases of the study (i.e., a main effect of task). To date, none of the research reviewed has explored the potential interaction between ADHD symptoms and WM load; therefore, an exploratory interaction was tested to examine the potential interaction between ADHD symptoms and WM load on social encoding. Additional secondary analyses of performance on the PONS as a function of n-back level were run to probe potential effects of WM load.

Method

Participants

Children and their parents were recruited via clinical referrals, posted advertisements, and in-person recruiting at camps, gyms, and local afterschool programs. Prior to coming into the lab, participants' parents completed a short phone screen and the Kiddie Schedule for Affective Disorders and Schizophrenia for School Aged Children (K-SADS) ADHD module to assess for ADHD symptoms. Exclusion criteria included a positive diagnosis of autism spectrum disorder or another developmental disorder, symptoms of psychosis, significant visual impairment, complicating medical conditions, a diagnosis of epilepsy or presence of seizures, or intellectual disability ($n = 0$) as reported by the child's parent. Further, participants were excluded if they had an estimated full scale IQ < 80 based on an abbreviated IQ assessment given in the laboratory ($n = 1$). These exclusion criteria were chosen due to the fact that individuals with these disorders and/or symptoms may have separate etiologies for their social functioning deficits than those with ADHD.

The sample consisted of 40 children (20 High ADHD, 20 Low ADHD) between the ages of 8 and 12 ($M = 9.82$; $SD = 1.48$). 55% of the children were male. Most of the sample was Caucasian (60%) with remaining participants

Table 1 Descriptive and demographic information for experimental groups and combined sample

	Group					
	Low ADHD (%)		High ADHD (%)		Combined (%)	
Female	22.5		22.5		45	
Male	27.5		27.5		55	
Race/ethnicity						
Caucasian*	37.5		22.5		60	
African American*	10		25		35	
Asian	2.5		0		2.5	
Hispanic/latino	0		2.5		2.5	
	M	*SD*	*M*	*SD*	*M*	*SD*
Age	9.55	1.47	10.10	1.48	9.83	1.48
WISC-IV block design	11.29	3.26	10.35	3.08	10.78	3.15
WISC-IV vocabulary	11.35	2.55	10.30	3.80	10.78	3.28

WISC Wechsler intelligence scale for children—fourth edition; scaled scores reported, *M* mean, *SD* standard deviation

*Chi square test significant between groups, $\chi^2(1) = 4.07$, $p = 0.04$

being African-American (35%), Asian (2.5%), or Hispanic/Latino (2.5%). Groups were matched on age, sex, and IQ, and t-tests and Chi square analyses revealed no significant differences on these variables (*p*s < 0.05). The groups were significantly different on race (coded as Caucasian vs. African-American), $\chi^2(1) = 4.07$, $p = 0.04$, with more African-American children in the High ADHD group than the Low ADHD group.[1] Descriptive and demographic information for the overall sample and each experimental group is displayed in Table 1.

Children were included in a High ADHD group if their parents reported clinically significant ADHD symptoms as evidenced by at least six of nine symptoms in one or more ADHD domain. Children were included in the Low ADHD group if their parents reported fewer than three symptoms of ADHD on the K-SADS ADHD module.

Measures

Behavior Rating Inventory of Executive Function—Parent Form (BRIEF-P) [53]. The BRIEF consists of 86 items that assess the parent's view of their child's self-regulation as reflected in specific problem behaviors at home and in school. It yields eight clinical scale scores, which load onto two indices: behavior regulation (inhibitory control, shifting, emotional control) and metacognition (initiation, working memory, planning and organization, organization of materials, and monitoring). Parent report-based *T* scores ($M = 50$, $SD = 10$) were used in the present study to provide measures of self-regulation deficits in everyday life. High internal consistency has been found for the BRIEF Parent form subscales (αs = 0.80–0.98). Internal consistencies for the current study were high and consistent with past studies (αs = 0.85–0.98).

Child Behavior Checklist for Ages 6–18 (CBCL) [54]. Attention problems and social competence were assessed via parents through the CBCL. The CBCL is a 113-item paper and pencil questionnaire completed by parents. Parents indicate how often the behavior listed for each item is true of their child using a three-point Likert scale (often/always true, sometimes true, and not true). Achenbach and Rescorla [54] reported high internal consistency for the Attention Problems ($\alpha = 0.86$) and Social Problems ($\alpha = 0.82$) constructs. In the current study, internal consistencies for CBCL constructs ranged from adequate ($\alpha = 0.72$; Rule Breaking) to high ($\alpha = 0.92$; Aggression Problems). The Attention Problems ($\alpha = 0.86$) and Social Problems ($\alpha = 0.74$) constructs both displayed good internal consistency.

Profile of Nonverbal Sensitivity (PONS) [51]. The PONS is a commonly used task of nonverbal social encoding and interpretation that has been validated in both clinical and non-clinical populations [51]. It consists of an adult female non-actor video-taped engaging in different scenes with an off-camera individual. Participants watch the scenes and choose what was happening in each scene among a set of answer choices. In children, the full PONS has an internal consistency between 0.86 and 0.90 [51] and is available in a child-friendly version, where answer choices are presented in more simplistic wording. The full PONS is 220 items and typically takes around 47 min to complete.

For the current study, the abbreviated face and body PONS was used instead. It comprises 40 items from the original measure consisting of silent video clips of facial expressions and body movements. The scene portrayals and answer choices fall into one of four categories: *submissive positive* (e.g., helping a customer), *submissive negative* (e.g., asking forgiveness), *dominant positive* (e.g., leaving on a trip), and *dominant negative* (e.g., expressing jealous anger). Studies comparing the child versions of the full PONS and the face and body PONS show similar properties, with accuracy on the full PONS ranging from 63.7 to 68.0% and accuracy on the shortened version averaging 67.3% [51]. Because it does not use any audio channels, the face and body PONS was chosen to avoid auditory interference with the n-back auditory task in the dual-condition of the study (see below for more details). Neuroimaging studies suggest that this task activates regions of the frontal lobes thought to be involved in WM [55]. Scores on the

[1] The low percentage of Asian and Hispanic/Latino participants prevented us from examining differences across all racial/ethnic groups in the study.

PONS have been found to correlate with a participant's popularity with peers, observer-rated "sensitivity," quality of same- and opposite-sex relationships, number of friends, speed in making friends, and understanding in relationships [51].

In the single-PONS phase, each trial consisted of a short pause (~ 5 s), followed by a cue indicating that the clip is about to start (~ 500 ms). Immediately following the presentation of the cue, the PONS clip played (~ 2 s), followed by another short pause (~ 5 s), at which point the answer choices were presented for the participant to read and respond by pressing the number keys 1, 2, or 3 (see Fig. 1). In line with Phillips et al. [43], a third answer choice was added to decrease the likelihood that a correct answer would be chosen by chance (i.e., chance guessing goes from 50 to 33% with the addition of a third choice). The third unoriginal answer choice was always chosen from the furthest vector in relation to the correct answer (e.g., for a correct answer in the dominant positive vector, a third incorrect answer would be chosen from the negative submissive vector) to minimize overlap with the correct answer.

N-back Task An n-back task is a commonly used WM task in which letters are presented one at a time, either on a computer screen (visual WM) or through computer speakers (auditory WM), and participants must respond to target letters either at the time of presentation (0-back) or when the target letter is the same as the letter presented one trial previous (1-back) or two trials previous (2-back). For example, in a 2 back trial, the task may present the letters T–X–L–X (target), where the participant should not respond to the first X but *should* respond to the second, because it matches the letter two trials previous.

In the current n-back task, all letters were presented through the participants' headphones in a male voice. The inter-stimulus interval was 2 s between the end of one letter and the beginning of the next, with a total of 6 letters presented in each trial. For each of the conditions (0-, 1-, & 2-back), a total of 72 letters were presented, with 18 target letters created using a random number generator to ensure no pattern in target letter presentation. Following the method of Phillips et al. [43], participants were asked to repeat each letter out loud unless it was a target letter, to which they should respond by saying "snap." In line with the aforementioned study [43], three letter sets (ZBQJ, XNTR, and FLHY) were used to ensure auditory distinction between letters in the same set.

Wechsler Intelligence Scale for Children-IV (WISC-IV) [56]. Intelligence was estimated using age-corrected scores on the Block Design and Vocabulary subtests from the WISC-IV. These two subtests are frequently used to estimate Full Scale IQ. They correlate 0.90 with the Full Scale IQ [56]. The WISC-IV is appropriate for youth between 6 and 16 years of age.

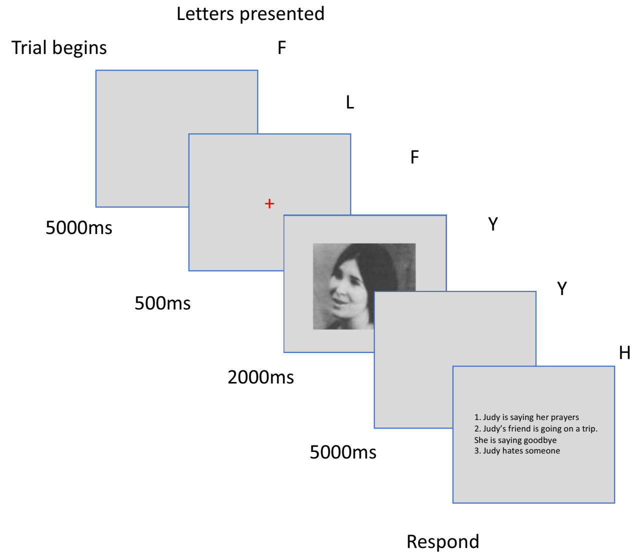

Fig. 1 Dual-task visual model. Letters presented are auditory; squares indicate visual stimuli appearing on a computer screen with stimulus presentation time indicated in milliseconds below

Procedure

Upon arriving to the research lab, informed consent and assent were obtained. Parents then completed observer-report measures of EF, social functioning, and ADHD symptomatology while their child completed IQ screening tasks, broadband questionnaires, and the experimental tasks of working memory and social encoding. Participants were randomized to complete either the dual-task condition first or the single-task n-back condition first, with the single-task PONS condition always completed in the middle as this procedure controlled for practice effects and fatigue on both the n-back and PONS. For the computerized tasks, participants were seated during the task and had a "rest phase" after each task where they completed questionnaires. The appointment lasted between 1 and 2 h, and upon completion of the study, families received a $50 Visa gift card as compensation for time and travel. Procedures were approved by the university IRB.

Task Detail

In the single-task conditions, participants completed an n-back working memory test and the Profile of Nonverbal Sensitivity (PONS) task separately to independently assess WM and social encoding abilities. As outlined in the Measures section above, the length of both single-task conditions was equal to ensure the most standardized comparison to the dual-task. In the dual-task phase, participants concurrently performed the n-back task while also completing the PONS.

Each trial during the dual-task phase consisted of six letters, less than one second in length each, presented 2 s apart (i.e., the n-back component), with the PONS clip appearing for 2 s in the middle of the trial between the n-back component. This resulted in the PONS clip overlapping with two of the letters each trial. Following the last presented letter, the answer choices were presented. In order to control for the possibility of reading difficulties affecting responses on the PONS, participants were given unlimited time to read and respond to each trial. Reaction times were recorded and no significant differences between groups were found (*ps* > 0.05) in average reaction time on either single- or dual-task trials. The next trial began immediately following a response by the participant.

Data Analysis

A power analysis was first conducted with GPower software version 3.1.9.2 [57]. Given relationships found in past studies for working memory [20, 32] and social encoding [37, 38] large effect sizes were expected between groups for both working memory and social encoding. For a large effect size ($f = 0.4$) using a repeated measures ANOVA, $\alpha = 0.05$, and power = 0.8, 40 total subjects would be needed to detect a between groups effect. Power analysis indicated 16 subjects would be needed for detecting the within group effect. Due to a lack of previous research on potential interaction effects of ADHD symptoms and WM load or incremental effect of WM load via n-back level, no power analyses were conducted for the secondary analyses. Overall, this power analysis suggested that our total sample of 40 would be appropriately powered for the main study analyses.

To test the study hypotheses, two main analyses were run. First, a series of t-tests with a Bonferroni correction compared those with High ADHD and Low ADHD on study variables. Second, two repeated-measures mixed model ANOVAs were run. For analyses of social encoding accuracy, the between group variable was group status (High ADHD vs. Low ADHD), the within group variable was condition (single vs. dual-task), and the DV was performance on the PONS task. A secondary analysis of social encoding accuracy as a function of n-back level was run to examine the effect of WM load on PONS accuracy across the two groups.

For analyses of WM performance, the between group variable was group status (High ADHD vs. Low ADHD), the within group variables were experimental condition (single vs. dual-task) and n-back level (0-back vs. 1-back vs. 2-back), and the DV was performance on the n-back task. Due to lack of differences on age, gender, and IQ, no covariates were included in the analyses. Analyses with and without race as a covariate showed no differences in results; therefore, analyses without covariates are reported below.

Results

For CBCL scales, independent samples t-tests with a Bonferroni correction revealed significant group mean differences between the High ADHD and Low ADHD groups for Attention Problems, Social Problems, Rule Breaking, and Aggressive Behavior (*ps* < 0.007; see Table 2). Analysis of subordinate scales for Externalizing Problems using Holm-Bonferroni correction revealed significant differences on the Rule Breaking Behavior and Aggressive Behavior scales (*ps* < 0.007). For all scales, the mean differences were in the expected direction, with the High ADHD group displaying higher levels of problems in each area. Notably, the largest effect sizes were for Attention Problems ($d = 3.90$) and Rule Breaking ($d = 2.03$).

For BRIEF-P scales, independent samples t-tests with a Bonferroni correction revealed significant differences on all scales (*ps* < 0.006; see Table 3) with the High ADHD group showing more problems in each area of EF. Notably, the largest effect sizes were for Working Memory ($d = 2.97$) and Inhibition ($d = 2.94$), the EFs thought to be most implicated in those with ADHD [20]. Means and standard deviations for all measures are reported in Tables 2 and 3.

Social Encoding

For the analysis investigating the effects of group and condition on participants' ability to accurately encode social cues, there was a significant main effect of condition, $F\ (1, 38) = 7.31$, $p = 0.01$, $\eta_p^2 = 0.16$,[2] with participants performing significantly worse on social encoding during the dual-task condition ($M = 17.43$; $SD = 3.54$; 48.41% correct) relative to the single-task PONS condition ($M = 19.30$; $SD = 3.57$; 53.4% correct). There was also a significant main effect of group, $F\ (1, 38) = 4.12$, $p = 0.05$, $\eta_p^2 = 0.10$, with individuals in the High ADHD group ($M = 17.50$; $SD = 2.87$; 48.60% correct) performing significantly worse on social encoding than individuals in the Low ADHD group ($M = 19.23$; $SD = 2.25$; 53.4% correct). The secondary analysis of a group x condition interaction was not supported, $F\ (1, 38) = 1.09$, $p = 0.30$, $\eta_p^2 = 0.03$.

Secondary analysis of PONS accuracy as a function of n-back level within the dual-task condition showed a main effect of group, $F\ (1, 38) = 5.14$, $p = 0.03$, $\eta_p^2 = 0.12$, with the Low ADHD group ($M = 6.23$; $SD = 0.97$; 51.92% correct) outperforming the High ADHD group ($M = 5.40$; $SD = 1.30$; 45.00% correct) on PONS accuracy. There was not a significant effect of n-back level, $F\ (2, 76) = 2.32$, $p = 0.11$,

[2] For partial eta squared, 0.01 = small, 0.06 = medium, and 0.14 = large.

Table 2 Means and standard deviations for CBCL syndrome scales

	Low ADHD		High ADHD		*t*	*p*	*d*
	M	*SD*	*M*	*SD*			
Anxious/depressed	55.47	8.60	61.10	7.88	− 2.08	0.05	0.68
Withdrawn/depressed	55.47	7.97	61.05	8.09	− 2.10	0.04	0.69
Somatic complaints	55.05	6.04	60.60	7.98	− 2.35	0.02	0.78
Social problems	53.53	6.41	61.05	6.15	− 3.63	0.001	1.20*
Attention problems	52.06	2.54	67.90	5.55	− 10.83	0.001	3.90*
Rule breaking	52.00	2.87	62.65	6.83	− 5.99	0.001	2.03*
Aggressive behavior	53.00	4.95	63.15	8.71	− 4.25	0.001	1.43*

M mean, *SD* standard deviation, *d* Cohen's d standardized difference effect size

*Difference is significant at the $p < 0.007$ level (2-tailed) using Bonferroni correction for multiple comparisons

Table 3 Means and standard deviations for BRIEF-P

	Low ADHD		High ADHD		*t*	*p*	*d*
	M	*SD*	*M*	*SD*			
Inhibit	45.65	8.14	68.20	7.16	− 8.97	0.001	2.94*
Shift	49.94	11.74	64.05	9.43	− 4.05	0.001	1.33*
Emotional control	48.82	12.59	64.40	10.98	− 4.02	0.001	1.32*
Initiate	46.76	8.65	63.15	9.31	− 5.51	0.001	1.82*
Working memory	45.18	6.32	69.45	9.69	− 8.84	0.001	2.97*
Plan/organize	44.00	8.36	64.30	11.39	− 6.08	0.001	2.03*
Organization of mat.	48.59	11.38	59.15	7.97	− 3.72	0.001	1.07*
Monitor	45.41	11.38	63.55	7.76	− 5.74	0.001	1.86*

M mean, *SD* standard deviation, *d* Cohen's d standardized difference effect size

*Difference is significant at the $p < 0.\ 0\ 06$ level (2-tailed) using Holm-Bonferroni correction for multiple comparisons

η_p^2=0.06, or group × n-back level interaction, F (2, 76) = 1.81, $p = 0.17$, η_p^2=0.05.

Working Memory

For the analysis investigating the effect of group, condition, and n-back level (i.e., 0-, 1-, or 2-back) on n-back total correct, the assumption of sphericity was violated to a small degree for n-back level and the n-back level x task interaction. Because the assumption of sphericity was only mildly violated, the less conservative Huynh–Feldt correction was used to interpret ANOVA results and is represented in the model degrees of freedom for these results.

First, a main effect of n-back level was found, F (1.61, 76) = 92.87, $p < 0.001$, η_p^2=0.71. Contrasts revealed that all three levels were significantly different, with these differences in the expected direction of 0-back performance (M = 16.68; SD = 1.52; 92.67% correct) better than 1-back performance (M = 15.18; SD = 2.25; 84.33% correct) and 1-back performance better than 2-back performance (M = 11.21; SD = 3.59; 62.28% correct). There was also a significant main effect of group, F (1, 38) = 6.35, $p = 0.02$, $\eta_p^2 = 0.14$, indicating that participants in the Low ADHD group (M = 15.14; SD = 1.78; 84.11% correct) performed significantly better than participants in the High ADHD group on the n-back (M = 13.58; SD = 2.14; 75.44% correct).

Finally, there was a significant interaction effect between n-back level and condition, F (1.76, 76) = 5.26, $p = 0.01$, η_p^2=0.12, indicating that performance on n-back level differed as a function of condition. Contrasts were performed comparing each level of the n-back to the single- or dual-task condition. The first contrast revealed that there was no difference between the 0-back and 1-back levels in the single- or dual-task conditions, F (1, 38) = 0.004, p = 0.95. In other words, participants' performance in the 0-back and 1-back conditions did not differ as a result of being in the single-task or dual-task phases of the study. The second and third contrasts revealed a significant difference of 0-back versus 2-back level, F (1, 38) = 5.60, p = 0.02, and 1-back versus 2-back level, F (1, 38) = 7.85, $p < 0.01$, as a function of single- or dual-task condition. These results showed that participants' performance on the 0-back and 1-back compared to the 2-back decreased at a sharper rate in the single-task condition than in the dual-task condition. There was no significant condition × level × group interaction.

Discussion

The current study sought to understand the role of WM in the encoding of nonverbal social cues in children with high and low symptoms ADHD. Our findings indicated that, in line with our first hypothesis, children with low ADHD symptoms had significantly lower levels of parent-reported attention problems, social problems, and self-regulation deficits than those with elevated ADHD symptoms. Children with high ADHD symptoms also exhibited higher parent-reported rule breaking behavior but those with low and high ADHD symptoms did not differ on parent- or child-reported internalizing problems. On experimental tasks, those with low ADHD symptoms also outperformed children with elevated ADHD symptoms on the social encoding task in both the single and the dual-task conditions, suggesting that children with elevated ADHD symptoms have greater difficulty encoding nonverbal social cues. This finding is consistent with past research, which has found that children with a diagnosis of ADHD have particular difficulty with the encoding of social cues [37, 38].

In relation to our second hypothesis, participants as a whole had more difficulty accurately encoding nonverbal social information when WM demands were increased during encoding trials. These findings are in line with previous research on the role of WM in social encoding. For example, as discussed earlier in this paper, Phillips et al. [43] found that increasing WM load on a dual-task impairs social encoding ability in normal adults. We found this to be true in children as well, suggesting some general role of WM in social encoding across the lifespan and for children with and without ADHD symptoms.

Our secondary analysis of a possible interaction effect revealed there is no significant interaction of ADHD symptoms and WM load. One explanation is that we were underpowered to detect what is possibly a smaller and more nuanced interaction effect of WM load and ADHD symptoms on social encoding accuracy. Alternatively, WM load may operate similarly in terms of social encoding impairment regardless of ADHD symptom level. Future studies may benefit from approaching this question using a large, dimensional sample of children to adequately address this question.

Though this study was focused on the effect of a dual-task WM design on social encoding, we also investigated the effect of the dual-task on n-back performance. Similar to the results of the social encoding analysis, we found that children with low ADHD symptoms outperformed children with elevated ADHD symptoms on the n-back task in both the single- and dual-task conditions. There was also a significant effect of n-back level, indicating that performance significantly decreased with each additional level of the n-back. Again, there was no interaction between group status and either the n-back level or condition. These results, coupled with the results of the social encoding analyses, suggest that children with elevated ADHD symptoms simply have lower baseline WM but their WM performance mirrors that of children with low ADHD symptoms as demand on their executive system increases.

Limitations and Future Directions

This study adds to the growing literature on the neurocognitive factors that contribute to social encoding in children with high and low ADHD symptoms; however, there are a few notable limitations. Despite a fairly appropriate representation of Caucasian and African American children in our sample, our study did not adequately represent other racial and ethnic groups, limiting the generalizability of our findings to those groups. The PONS is currently the best available measure utilizing dynamic scenes to portray nonverbal information but has some limitations. Most importantly, the PONS uses an adult female non-actor to portray the scenes. Children may interpret nonverbal information coming from adults differently than same-aged peers, and future studies would benefit from the inclusion of child targets to evaluate these potential differences.

Despite being adequately powered to detect overall group differences, our sample may have been too small to detect additional interaction effects. For example, despite no differences on internalizing problems, our groups differed significantly on various externalizing problems (e.g., Rule Breaking) but our study was underpowered to consider additional covariates. In a recent meta-analysis of social functioning in children with ADHD, researchers found that effect size differences in the social skills domain were significantly smaller in studies that controlled for conduct problems (CP), though CP did not significantly moderate the effect size difference in the domains of peer functioning or SI [58]. Despite these findings and our study's focus on a facet of SIP, examining potential moderators, like externalizing problems, is still an important area for empirical examination in this line of research. Future studies would benefit from a larger sample size to investigate smaller effects, additional covariates, and potential interactions between group status and study variables that may exist.

Finally, our study focused on children with either high or low symptoms of ADHD. Future studies may wish to explore more carefully diagnosed participants who would meet full diagnostic criteria for ADHD and control for other variables that could affect study outcomes, such as history of head trauma, exposure to toxins, and pregnancy complications. Despite parents of participants in the High ADHD group reporting six or more symptoms of ADHD on the KSADS, the CBCL showed our sample to be in the Borderline severity range on Attention Problems and just within the Normal range on Social Problems. As such, the effects found in the current study may not fully represent effects that may be found with a more severe or clinical sample. Alternatively, dimensional approaches may be fruitful given the movement towards examining cross-cutting processes across diagnoses (e.g., the National Institute of Mental Health's RDoC initiative).

In regard to the dual-task paradigm, this study would have benefitted from the addition of other well-established measures of WM to strengthen the argument that it is WM interference causing decreases in social encoding accuracy. The n-back may be loading only a particular facet of a multifaceted WM construct [59, 60], which may be a different facet than that required for encoding social information. There is currently some debate in the experimental literature regarding the n-back task versus complex span in measuring WM [61–63], so future studies would benefit from the inclusion of both measures to better understand the relationship between different aspects of WM and social encoding.

Summary

This study lends support to a role of WM in social information processing, specifically the encoding of nonverbal cues, and helps to establish a causal relationship between these variables. It appears that children with high levels of ADHD symptoms may simply possess lower WM ability, but they are still able to employ this cognitive skill to a degree that parallels children with low ADHD symptoms as executive load increases. In addition to informing basic neurocognitive models of social functioning, this study also supports the move in the field to study cognitive training interventions aimed at improving EF deficits [64, 65]. Conceptually speaking, the results of this study suggest that if WM deficits can be improved, we may find a subsequent decrease in social encoding deficits, even under mild levels of cognitive load. Further study of these processes may help refine our theories of EF and interventions for EF deficits and social problems.

Funding This study was not funded by any outside source or agency.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants in the study.

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