Are Emotion Recognition Abilities Intact in Pediatric ADHD?

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Abstract

Extant studies suggest that children with ADHD may make more errors and respond more slowly on tasks that require them to identify emotions based on facial affect. It is unclear, however, whether these findings reflect a unique deficit in emotion recognition, or more general difficulty with choice-response tasks (i.e., tasks that require participants to select among a set of competing options). In addition, ADHD is associated with executive dysfunction, but there is inconsistent evidence regarding the extent to which top-down cognitive control is involved in emotion recognition. The current study used a series of four counterbalanced tasks to systematically manipulate emotional content and working memory demands to determine (a) whether children with ADHD exhibit a unique facial affect recognition deficit, and (b) the extent to which facial affect recognition is an automatic vs. controlled process that depends in part on working memory. Bayesian results from a carefully-phenotyped sample of 64 children ages 8–13 (M=10.42, SD=1.56; 26 girls; 67% Caucasian/Non-Hispanic) with ADHD (n=35) and without ADHD (n=29) indicated that working memory is involved in children's ability to efficiently infer emotional state from facial affect ($BF_{10}=4.59\times10^{14}$). Importantly, there was significant evidence *against* deficits in emotion recognition for children with ADHD. The ADHD/Non-ADHD groups were statistically equivalent in terms of recognition accuracy ($BF_{01}=1.32\times10^{54}$, $d= -0.18$), and the ADHD group's slower recognition speed was parsimoniously explained by difficulty with choice-response tasks rather than unique to emotional stimuli ($BF_{10}=3.23$, $d=0.31$). These findings suggest that emotion recognition abilities are intact in children with ADHD, and highlight the need to control for impaired bottom-up (choice-response) and top-down abilities (working memory) when investigating emotional functioning in ADHD.

Keywords

ADHD; facial affect; emotion recognition; choice-response; working memory

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Attention-deficit/hyperactivity disorder (ADHD) is a heterogeneous neurodevelopmental disorder comprised of clinically elevated and impairing symptoms of inattention and/or hyperactivity/ impulsivity, present in approximately 5% of school-aged children (Polanczyk et al., 2014). A majority of children with ADHD also experience clinically significant and impairing social problems (e.g., DuPaul et al., 2001; Huang-Pollock et al., 2009; McConaughy et al., 2011). Conceptual models of ADHD converge in describing social problems as secondary outcomes of the disorder, but diverge in the underlying mechanisms and processes proposed to cause these difficulties. Across models, these social performance impairments (de Boo & Prins, 2007) are viewed as secondary to the impairing nature of inattentive and hyperactive/impulsive behaviors (Landau & Moore, 1991), to unique and potentially interactive effects of higher-order impairments in executive functions such as working memory (Kofler et al., 2018) and inhibitory control (Bunford et al., 2014), and/or to more basic impairments in emotion recognition and regulation (Bunford, Evans, & Wymbs, 2015; Graziano & Garcia, 2016). The current experiment focuses on emotion recognition and working memory in children with ADHD to determine the extent to which (1) ADHD is associated with a unique deficit in emotion recognition, and (2) this hypothesized deficit is evoked or exacerbated by task demands that challenge these children’s well-documented working memory impairments (Kasper et al., 2012).

Emotion Recognition in ADHD

A critical yet understudied prerequisite for effective social interaction is accurate facial affect recognition, or emotion recognition, which contributes to emotional knowledge, social competence (Trentacosta & Fine, 2010), active participation in social environments, successful interactions with others (Morris, Weickert, & Loughland, 2009), and theory of mind/perspective-taking development in children and adolescents (Korkmaz, 2011). Emotion recognition refers to one’s ability to accurately identify another’s emotional state based on their nonverbal facial expression and corresponding bodily postures, and is often studied using basic facial affect recognition tasks (Graziano & Garcia, 2016). Facial affect recognition tasks typically involve asking participants to select the emotion name that matches the facial expressions shown in photographs of models demonstrating discrete basic emotions (anger, fear, sadness, joy, disgust, surprise; e.g., Ekman, 1992). These choice-response tasks have been used extensively to study basic emotion recognition in a wide range of clinical populations that includes children, adolescents, and adults with schizophrenia (Brune, 2005; Hooker & Park, 2002), schizotypal symptoms (Shean et al., 2007), autism spectrum disorder (Baron-Cohen et al., 1997, 1999; Harms, Martin, & Wallace, 2010), traumatic brain injury (Babbage et al., 2011; McDonald, 2013; Williams & Wood, 2010), and ADHD (Collin et al., 2013; Uekermann et al., 2010).

Most relevant for the current study, findings in the pediatric ADHD literature are mixed. Numerous studies have reported that children and adolescents with ADHD are impaired on choice-response tasks that involve identifying emotions based on facial affect (Boakes, et al., 2008; Da Fonseca et al., 2009; Pelc et al., 2006; Shin et al., 2008; Sinzig, Morsch, & Lehmkuhl, 2008), while others have reported non-significant differences on similar emotion recognition tasks (Berggren et al., 2016; Downs & Smith, 2004; Greenbaum, Stevens, Nash, Koren, & Rovet, 2009; Guyer et al., 2007; Passarotti et al., 2010). A recent meta-analysis found overall medium-magnitude emotion recognition impairments in ADHD (d=0.64), while noting that this effect may or may not be specific to emotion recognition due to uncontrolled confounds in the reviewed studies (Graziano & Garcia, 2016). The current study addresses these confounds and is the first to experimentally manipulate demands on both basic emotion recognition and higher-order working memory to clarify the presence and specificity of emotion recognition deficits in ADHD.

Choice-Response Task Performance in ADHD

The reason for the discrepant findings in this literature is unclear, but one possibility relates to the influence of impairments in more basic neurocognitive abilities that are required for successful performance on facial affect recognition tasks. For example, children with ADHD show impaired performance on a wide range of tasks that involve selecting a response based on the stimulus presented, regardless of task content (for review, see Kofler et al., 2013). These tasks are commonly termed *choice-response tasks* and require children to attend to stimuli and select among a set of competing options based on a rule set. As such, it is possible that their poor performance in most emotion recognition studies may be parsimoniously explained by more general difficulties with choice-response tasks rather than actual impairments in their ability to identify basic human emotions. This methodological artifact may be particularly salient for children with ADHD because, to our knowledge, no study of facial affect recognition in ADHD has included control task(s) to disassociate emotion-specific performance from more general performance difficulties (Da Fonseca et al., 2009; Shin et al., 2008). In other words, it is possible that the poor performance of children with ADHD on emotion recognition tasks may be attributable to difficulties applying a rule set to select among competing response options (i.e., the non-emotional aspects of the tasks) rather than to actual difficulties recognizing human emotions. Thus, at this time we cannot conclude with any certainty that the poor performance of children with ADHD on facial affect recognition tasks has anything to do with their ability to identify emotions.

Working Memory Deficits in ADHD

Poor performance on emotion recognition tasks among children with ADHD may also relate to higher-order impairments in executive functions such as working memory (Kofler et al., 2018). Working memory is a limited capacity, multicomponent system that involves the updating, manipulation/reordering, and dual-processing of internally-held information for use in guiding behavior (Baddeley, 2007; Engle et al., 1999; Wager & Smith, 2003). Mounting evidence suggests that a majority of children with ADHD may have impaired working memory (e.g., Kasper et al., 2012), and these working memory impairments have been linked experimentally with inattention and hyperactivity (Hudec et al., 2015; Kofler et al., 2010; Patros et al., 2017; Rapport et al., 2009). Additionally, working memory predicts social problems generally (Bunford et al., 2014; Kofler et al., 2011), and social performance difficulties in ADHD specifically (Kofler et al., 2018), making it an appealing candidate for explaining difficulties with emotion recognition and other basic processes necessary for adept social interaction (Phillips et al., 2008; Kofler et al., 2011). Particularly in the context of the complex back-and-forth nature of social interactions that tax children's capacity-limited working memory system (Phillips et al., 2007), it seems reasonable to hypothesize that children with ADHD experience difficulty effectively decoding facial expressions as a byproduct of competing demands to mentally store and manipulate other relevant information (Aduen et al., 2018). At the same time, the evidence is mixed with regard to whether facial affect recognition is an automatic process that is independent of, or controlled/influenced by, top-down working memory processes (for reviews, see Dickstein & Castellanos, 2011; Lindquist et al., 2012).

Dual-task methodologies, which experimentally assess the extent to which increasing demands on a candidate causal process (working memory) disrupts performance on a hypothesized outcome of that process (emotion recognition), appear well-suited to address the extent to which working memory directly facilitates children's facial affect recognition (Kofler et al., 2018). This methodology relies on the limited capacity of human cognitive systems, is used extensively to develop and refine models of human cognition (e.g., Baddeley, 2007), and allows conclusions regarding the extent to which mental processes compete for the same neurocognitive resources (Wang & Gathercole, 2013). For example, finding that concurrent working memory demands disrupt emotion recognition would indicate that children rely, at least in part, on the same neurocognitive system for temporarily holding information (i.e., working memory) as they do for inferring someone's emotional state based on that person's affect (i.e., emotion recognition). In other words, this finding would suggest that processing facial expressions for emotional content occurs at least in part within working memory (Wang & Gathercole, 2013). In contrast, finding that children's emotion recognition performance is unaffected by concurrent working memory demands would potentially indicate that face processing and working memory rely on functionally distinct neurocognitive systems and lend support to the hypothesis that working memory's relation with emotion recognition is non-causal (Kofler et al., 2018).

Current Study

The current study is the first to experimentally assess both methodological confounds (choice-response errors vs. errors specific to emotion recognition) and top-down impairments (working memory abilities) as explanatory mechanisms underlying the replicated but inconsistent evidence linking ADHD with deficits in basic facial affect (emotion) recognition. To begin addressing the presence/absence of, and mechanisms associated with, emotion recognition deficits among children with ADHD, the current study systematically manipulated working memory demands and emotional content across a series of four counterbalanced tasks that were identical in all aspects except the target mechanisms (facial affect recognition demands no/yes × working memory demands low/high). Similar to prior work, children completed a facial affect recognition task that involved identifying six basic emotions (anger, fear, sadness, joy, disgust, surprise; Graziano & Garcia, 2016). To our knowledge this is the first study of children with ADHD to include an otherwise identical task that adds concurrent working memory demands, as well as control tasks that present non-affective stimuli to disassociate emotion recognition from general choice-response deficits in children with ADHD.

We hypothesized that children with ADHD would make more errors and respond more slowly on the choice-response tasks (i.e., emotion and animal/non-emotion recognition) than the Non-ADHD group. Evidence for a unique emotion recognition deficit in ADHD would be indicated by disproportionate decreases in accuracy and/or speed during the facial affect recognition task relative to the animal recognition task (i.e., a significant group × condition interaction), thereby indicating that their impairments could not be more parsimoniously explained by general task demands. We also hypothesized that adding concurrent working memory demands would disrupt facial affect recognition accuracy/speed, and that this manipulation would disproportionately affect the ADHD group due to their well-documented working memory impairments (Kasper et al., 2012). In other words, we predicted that facial affect recognition is at least partially a controlled (non-automatic) ability that is processed in part within the working memory system (Baddeley, 2007). Evidence supporting top-down influences on facial affect recognition would include condition × working memory interaction(s) for speed and/or accuracy that indicate differential effects of adding working memory demands during facial affect recognition tasks relative to otherwise-identical control tasks that include familiar stimuli (i.e., identifying clearly presented archetypes of common animals; Eimas & Quinn, 1994; Shiffrin & Schneider, 1977). Finally, given the mixed evidence for emotion recognition deficits in children with ADHD, we used Bayesian statistics because they can provide evidence supporting the null hypothesis rather than just failing to reject it (e.g., Wagenmakers et al., 2016).

Method

Open Data

The de-identified raw dataset (.jasp) and detailed results output are available at: https://osf.io/pc3zv/

Participants

The final sample comprised 64 children aged 8 to 13 years (*M*=10.42, *SD*=1.56; 38 boys, 26 girls) from the Southeastern United States, drawn from an initial sample of 71 children recruited by or referred to a children's learning clinic (CLC) through community resources between 2015 and 2017 (7 children were assessed but excluded as detailed below). Psychoeducational evaluations were provided to the parents of all participants. All parents and children gave informed consent/assent, and we obtained Institutional Review Board approval prior to beginning data collection. Sample ethnicity was mixed with 43 Caucasian/Non-Hispanic (67.2%), 9 Hispanic/English-speaking (14.1%), 5 African American (7.8%), 3 Asian (4.7%), and 4 multiracial children (6.3%).

Group Assignment

All children and their parents participated in a detailed, semi-structured clinical interview using the Kiddie Schedule for Affective Disorders and Schizophrenia for School-Aged Children (K-SADS; Kaufman et al., 1997). The K-SADS (2013 Update) allows differential diagnosis according to symptom onset, course, duration, quantity, severity, and impairment in children based on DSM-5 criteria (APA, 2013), and was supplemented with parent and teacher ratings scales from the Behavior Assessment System for Children (BASC-2; Reynolds & Kamphaus, 2004) and Child Symptom Inventory (CSI-IV; Gadow & Sprafkin, 2002).

Thirty-five children met all of the following criteria and were included in the ADHD group (n=35; 37% girls): (1) DSM-5 diagnosis of ADHD Combined (n=24), Inattentive (n=9), or Hyperactive/Impulsive Presentation (n=2) by the directing clinical psychologist based on K-SADS; (2) borderline/clinical elevations on at least one parent and one teacher ADHD rating scale, and (3) current impairment based on parent report. All ADHD subtypes/presentations were eligible given the instability of ADHD subtypes (Valo & Tannock, 2010). Psychostimulants ($N_{prescribed}$=10) were withheld ≥24 hours for neurocognitive testing. To improve generalizability (Wilens et al., 2002), children with ADHD and comorbid anxiety disorders (20.0%), depressive disorders (5.7%), and oppositional defiant disorders (11.4%) were included.[1]

The Non-ADHD group comprised 29 consecutive case-control referrals who did not meet ADHD criteria, and included both neurotypical children and children with psychiatric disorders other than ADHD. Neurotypical children (69%) had normal developmental histories and nonclinical parent/teacher ratings and were recruited through community resources. Clinically-referred and evaluated children who did not meet ADHD criteria were also included in the Non-ADHD group. These Non-ADHD disorders were included to account for performance patterns that may be driven by general psychopathology, rather than ADHD specifically. Best estimate diagnoses included anxiety disorders (20.7%), depressive disorders (6.9%), and oppositional defiant disorder (3.4%). The ADHD and Non-ADHD groups were equivalent in the proportion of children diagnosed with a clinical disorder other than ADHD both overall (BF_{01}=78.71) and across diagnostic categories (anxiety: BF_{01}=4.04; depression: BF_{01}=6.32; ODD: BF_{01}=3.31). Learning disabilities were suspected in 17.1% of ADHD and 6.9% of Non-ADHD cases based on score(s) >1 SD below age-norms on the Kaufman Test of Educational Achievement (KTEA-3; 2014) Academic Skills Battery Reading and Math Composites (BF_{01}=2.47).[1]

Children were excluded from the study if they presented with gross neurological, sensory, or motor impairment; non-stimulant medications that could not be withheld for testing; or seizure disorder, psychosis, intellectual disability, or autism spectrum disorder (n=5). Two additional cases were excluded for below criterion performance on the reading comprehension component (≥ 70% of items correct) as recommended to ensure the integrity of the high working memory conditions described below (Conway et al., 2005), resulting in the final sample of 64 (35 ADHD, 29 Non-ADHD).

Procedures

Testing occurred during a larger battery of two, 3-hour sessions. Tasks were counterbalanced within and across sessions to minimize order/fatigue effects. Children received brief breaks after each task, and preset longer breaks every 2–3 tasks to minimize

[1]As recommended in the KSADS, ODD was diagnosed only with evidence of multi-setting symptoms/impairment. The pattern and interpretation of results is unchanged if children with learning disabilities are excluded.

fatigue. Performance was monitored at all times by the examiner, who was stationed just outside of the testing room (out of the child's view) to provide a structured setting while minimizing performance improvements associated with examiner demand characteristics (Gomez & Sanson, 1994).

Experiment Overview

A series of 4 computerized tasks were created to experimentally address the presence/ absence of, and mechanisms associated with, emotion recognition deficits in ADHD. Task stimuli were chosen to provide robust manipulation of emotion identification and working memory demands while also providing experimental data to address secondary questions regarding reading skills and information processing abilities in ADHD. The 4 tasks were designed to vary systematically in a fully-crossed experiment that includes one task each per emotion identification (no, yes) × working memory (low, high) combination (Figure 1). As described below, a basic facial affect recognition task was paired with an otherwise identical task that presented common animals instead of facial expressions to evaluate the extent to which hypothesized impairments on the facial affect recognition task were more parsimoniously explained by choice-response demands independent of the task's emotional content. To evaluate the role of ADHD-related working memory impairments on their hypothesized emotion recognition deficits, these emotion and animal recognition tasks were in turn paired with complex span versions that were identical to their paired recognition variant but with added working memory demands (Figure 1). Performance on the secondary reading component of the animal tasks (described below) is reported for this sample in Kofler et al. (2018) to investigate conceptually distinct hypotheses; performance on the primary emotion/animal identification components has not been previously reported.

Task Stimuli

Facial affect stimuli.—The computerized facial affect recognition tasks used in the current study included high quality photographs of children demonstrating six basic emotions: happiness, anger, sadness, fear, surprise, and disgust (Ekman, 1992). Pictures were obtained from the Dartmouth Database of Children's Faces (Dalrymple, Gomez, & Duchaine, 2013). All children were professionally photographed in front of a black background, with only the face visible (hair hidden by black knit caps). The 40 best exemplars of each emotion were selected for the current study, using a multi-phase selection process, with the requirement that there be an equal number of boy and girl models for each emotion. First, we selected the 40 boy and 40 girl models judged by Dalrymple and colleagues (2013) to produce the best exemplars of the intended emotions. Next, members of our study team independently selected the best exemplar for each model, for each emotion. Finally, these candidate photos were viewed by all members of the study team and retained based on consensus of the intended emotion. Forty exemplars of each emotion (20 boys, 20 girls) were retained, and randomly assigned to the Emotion Recognition and Emotion Span tasks (10 boys, 10 girls per emotion, per task).

Animal stimuli.—Animal pictures were selected for the control tasks to create choice-response tasks that were closely matched to the emotion tasks in terms of children's high familiarity with the stimuli (Eimas & Quinn, 1994), use of high-quality, same-sized color photographs, and an identical number of discrete categories. The animal stimuli included six distinct animals selected by our research team: dogs, spiders, birds, fish, lions, walruses. Each animal stimulus depicted a single exemplar of the target animal (Figure 1, top left). Pictures were obtained from Internet searches conducted by undergraduate research assistants. Forty high-quality, color exemplars of each animal were retained based on consensus by the study team, and randomly assigned to the Animal Recognition and Animal Span tasks. None of the participants had Specific Phobia(s) of any animals.

Reading stimuli.—The reading stimuli included 196 age-appropriate true/false sentences from the Woodcock-Johnson Tests of Academic Achievement (WJ-III Forms A and B; Woodcock et al., 2001) Reading Fluency subset. These simple sentences were used to provide age-appropriate silent reading material. Task instructions differed from the WJ-III and emphasized accurate responding rather than speed.

Task Overview

Thirty-six total trial pairs were completed for each task, in addition to eight practice trial pairs administered prior to advancing to the full task (100% correct required). Each trial pair included identification of one primary stimuli (emotion or animal) followed by one distractor stimuli (true/false sentence). During the high working memory tasks described below, a recall phase was inserted after every 3–6 trial pairs (8 total recall phases, with 2 recall phases each at memory set sizes 3–6). The number of trial pairs before each recall phase was unpredictable to maximize working memory demands as recommended (i.e., mixed presentation; Kofler et al., 2015). The recall phase was omitted during the low working memory tasks. Children whose counterbalancing resulted in them completing either or both of the low working memory tasks after the high working memory task(s) were explicitly told not to remember the emotions/animals.

Following Engle et al. (1999), children received performance feedback during both the primary and secondary task components. All tasks were self-paced. The primary dependent variables for each task were the percentage of correctly identified emotions (accuracy; % correct out of the 36 total facial affect stimuli presented) and response times (speed; milliseconds) during the primary recognition phase. Internal consistency reliability in the current sample was α = .84-.89 for the high working memory conditions and α = .89-.90 for the low working memory conditions.

High Working Memory Conditions (Emotion Span, Animal Span)

We created two variants of the reading span task described by Conway et al. (2005), adapted for use with children. Our emotion and animal working memory (complex span) tasks both exemplify dual-processing working memory based on the Engle et al. (1999) model. These complex span tasks alternate the presentation of to-be-remembered target stimuli (emotion or animal names), with a demanding, secondary processing task (Conway et al., 2005). Engaging in a secondary task (silent reading) of the same modality as the target stimuli (emotion or animal names) yields interference effects that increase demands on central executive working memory, because both processes rely on the same limited-capacity phonological store (Conway et al., 2005). Comparisons of ADHD and typically developing groups indicate medium to large magnitude between-group differences on similar complex span tasks (Kuntsi et al., 2001; Willcutt et al., 2001). Evidence for reliability and validity of working memory complex span tasks includes high internal consistency ($\alpha = 0.77$ to 0.81), 3-month test-retest reliability of .70 to .80, and expected relations with other measures of working memory (Conway et al., 2005).

Emotion span.—Children were sequentially shown screens containing a single facial affect photograph at the top of the screen and six response boxes on the bottom of the screen (Figure 1, right). Children were instructed to click the response box that matched the picture (e.g., clicking 'surprised' when the model's facial expression indicated surprise). After each emotion, children silently read and responded to a true/false sentence by clicking the corresponding button on screen. After a predetermined number of emotion-sentence pairs (set sizes 3, 4, 5, and 6), children were asked to recall the emotions in serial order. The emotions were presented first in each emotion-sentence pair to ensure interference effects between the final emotion and the recall phase (Unsworth & Engle, 2007). Each emotion was shown a maximum of one time prior to each recall phase. The exemplar of each emotion was selected randomly within each trial.

Animal span.—The animal span task was identical to the emotion span task described above, except that children identified and recalled the animal stimuli instead of the facial affect stimuli (Figure 1, left).

Low Working Memory Conditions (Emotion Recognition, Animal Recognition)

Facial affect recognition (emotion recognition).—The emotion recognition task was identical to the emotion span task described above, except that children were not required to remember the emotion names (i.e., the recall phase was omitted; Figure 1, bottom).

Animal recognition.—The animal recognition task was identical to the emotion recognition task described above, except that children identified animals instead of emotions.

Intellectual functioning (IQ) and Socioeconomic Status (SES)

All children were administered the Wechsler Intelligence Scale for Children, 5th edition (Wechsler, 2014) Verbal Comprehension Index (VCI) to obtain an estimate of intellectual functioning. SES was estimated using the Hollingshead (1975) scoring based on caregiver(s)' education and occupation.

Bayesian Analyses

Bayesian analyses were selected because they allow stronger conclusions by estimating the magnitude of support for both the alternative and null hypotheses (Rouder & Morey, 2012). That is, Bayesian methods can confirm the null hypothesis rather than just fail to reject it (Wagenmakers et al., 2016). Bayes factor mixed-model ANOVAs with default prior scales (Rouder & Morey, 2012; Wagenmakers et al., 2016) were conducted using JASP 0.8.5 (JASP Team, 2017). Instead of a *p*-value, these analyses provide BF_{10}, which is the Bayes Factor of the alternative hypothesis (H_1) against the null hypothesis (H_0). BF_{10} is an odds ratio, where values at/above 3.0 are considered moderate evidence supporting the alternative hypothesis (i.e., statistically significant evidence for group differences). BF_{10} values above 10.0 are considered strong (>30=very strong, >100=decisive/extreme support; Wagenmakers et al., 2016).

Conversely, BF_{01} is the Bayes Factor of the null hypothesis (H_0) against the alternative hypothesis (H_1). BF_{01} is the inverse of BF_{10} (i.e., $BF_{01}=1/BF_{10}$), and is reported when the evidence indicates a lack of an effect (i.e., favors the null hypothesis; Rouder & Morey, 2012). BF_{01} values are interpreted identically to BF_{10} (≥3.0=moderate, >10.0=strong, >100=decisive support for the null hypothesis that the ADHD and Non-ADHD groups are *equivalent* on an outcome; Rouder & Morey, 2012).

Data Analysis Overview

The current study used a fully-crossed 2×2 experimental design (emotional content no/yes × working memory demands low/high) with two groups (ADHD, Non-ADHD). We thus examined the study's primary hypotheses via Bayesian mixed-model ANOVAs to determine (a) the extent to which children with ADHD exhibit a unique facial affect recognition deficit that cannot be explained by task-related choice-response processes, and (b) the extent to which facial affect recognition processes are automatic vs. controlled processes that depend on working memory, and/or are only impaired in children with ADHD under conditions that tax their underdeveloped working memory system. Separate mixed-model ANOVAs were conducted for accuracy (% emotions/animals identified correctly) and speed (response time). For each Bayesian mixed-model ANOVA, the best fitting model was selected (criteria: combination of main and interactions effects with highest $BF_{10} \geq 3$), and each additional effect was tested relative to this best-fitting model (Rouder & Morey, 2012). Exploratory analyses separated by emotion type (anger, fear, sadness, joy, disgust, surprise) are presented in the Supplementary Online section; results were highly consistent across emotion type.

Interpretation of results is unchanged if classic null hypothesis significance testing (NHST) is used instead of Bayesian analyses (except that non-significant *p*-values cannot be interpreted as evidence of equivalence). We were unable to analyze effects of the number of stimuli presented (i.e., memory set sizes 3–6) as an additional within-subjects factor during the high working memory conditions because (1) there were only two trials per memory set, and (2) presentation was mixed, such that children did not know how many stimuli would be presented on any given trial. Mixed presentation was selected by design because it maximizes central executive working memory demands by minimizing strategies associated with knowing the memory set (Kofler et al., 2015).

Results

Bayesian Power Analysis

A simulation study was conducted to estimate power for between-group tests using the R BayesFactor package and BayesianPowerTtest script (Lakens, 2016) optimized by Zimmerman (2016), with parameters as follows (N=64; r-scale=1; k=100,000 simulated experiments; BF threshold=3.0). Results indicated power=.81 for supporting the alternative hypothesis of impaired working memory in ADHD based on a true effect of *d*=0.74 (meta-analytic estimate for ADHD/Non-ADHD working memory differences from Kasper et al., 2012; 81% of simulations correctly supported H_1 at $BF_{10} \geq 3.0$, 18% provided equivocal support at BF_{10} values between 1/3 and 3, and only 1% incorrectly supported H_0). Similarly, results indicated power=.63 for supporting the alternative hypothesis of impaired emotion recognition in ADHD based on a true effect of *d*=0.64 (meta-analytic estimate for ADHD/Non-ADHD emotion recognition differences from Graziano & Garcia, 2016; 63% of simulations correctly supported H_1 at $BF_{10} \geq 3.0$, 33% provided equivocal support at BF_{10} values between 1/3 and 3, and only 4% incorrectly supported H_0). For both emotion recognition and working memory, power=.74 for supporting the null if true (i.e., for *d*=0.0; 74% of simulations supported H_0, 25% provided equivocal support, and only 1% incorrectly supported H_1). Taken together, our false positive rate is between 1% and 4% across simulations (i.e., low odds of incorrectly supporting the null hypothesis if the alternative hypothesis is true, and vice versa), suggesting adequate power.

Of note, these Bayesian power estimates are for single variable comparisons (i.e., independent samples t-tests) and thus do not account for the increased power obtained by our use of multiple tasks per outcome. To our knowledge, Bayesian power analysis for mixed-model ANOVA is not yet available. Power analysis based on traditional NHST, with alpha=.05, power=.80, 2 groups (ADHD, Non-ADHD), and 4 measurements (emotion content yes/no × working memory low/high) indicates that our *N*=64 can reliably detect between-group effects of *d*=0.28, within-group effects of *d*=0.15, and group × condition interaction effects of *d*=0.15 or larger. Thus, the study is sufficiently powered to address its primary aims.

Preliminary Analyses

Outliers ≥3 *SD* were winsorized relative to the within-group distribution (ADHD, Non-ADHD) as recommended (Tabachnick & Fidell, 2007). This process affected 0.68% of outcome data points. The ADHD group demonstrated impaired working memory across the complex span working memory tasks (*d*=0.56, BF_{10}=3.88), as expected. In contrast, the groups were equivalent with regards to age (BF_{01}=3.12) and did not differ significantly based on gender (BF_{01}=2.77), SES (BF_{10}=1.90), or IQ (BF_{10}=1.14); we therefore report simple model results with no covariates.

Emotion Identification Accuracy

The 2 (group: ADHD, Non-ADHD) × 2 (condition: Animal, Emotion) × 2 (working memory: Low, High) Bayesian mixed-model ANOVA provided the strongest support for the model that included a main effect of condition only ($BF_{10}=3.21\times10^{53}$, Cohen's *d*=2.46). Relative to this model, there was significant evidence *against* main effects of group ($BF_{01}=1.32\times10^{54}$, *d*= −0.18) and working memory ($BF_{01}=2.39\times10^{54}$, *d*= −0.03). With reference to the main effects model, there was also significant evidence against interactions of group × condition (BF_{01}=4.83), group × working memory (BF_{01}=3.97), condition × working memory (BF_{01}=4.95), and the 3-way interaction (BF_{01}=3.06). In other words, identifying basic emotions was more difficult/less automatic than recognizing common animals, but the ADHD and Non-ADHD groups showed equivalent accuracy rates. In addition, adding concurrent working memory demands did not reduce accuracy rates for either group (Figure 2, top).

Emotion Identification Speed

The 2 (group: ADHD, Non-ADHD) × 2 (condition: Animal, Emotion) × 2 (working memory: Low, High) Bayesian mixed-model ANOVA provided the strongest support for the model that included condition, group, working memory, and the condition × working memory interaction (BF_{10}=4.59×10^{14}). Relative to this model, there was significant evidence *against* the group × working memory interaction (BF_{01}=3.39) and the 3-way interaction (BF_{01}=3.43). There was insufficient evidence for or against the group × condition interaction (BF_{01}=1.49). In other words, children with ADHD required more time to accurately identify basic emotions, but this effect was more parsimoniously explained by their generally slower performance on choice-response tasks (i.e., they did not perform differentially slower when identifying emotions than when identifying common animals). Working memory is involved in the identification of basic emotions and recognition of common animals, as evidenced by both groups' significantly longer response times during the high working memory conditions. Post-hoc tests for the working memory × condition interaction (Figure 2, bottom) suggest that converting non-affective visual images to phonological code (i.e., animal recognition) is a more automatic process than processing facial expressions for emotional content, as evidenced by disproportionate slowing during the animal (d= −0.65, BF_{10}=2.27×10^4) relative to emotion task (d= −0.30, BF_{10}=2.70) when concurrent memory demands were added, resulting in large response time differences between the emotion and animal tasks under low working memory demands (d= −1.13, BF_{10}=2.79×10^{11}) but medium differences under high working memory conditions (d= −0.55, BF_{10}=1.18×10^3).

Taken together, results of the accuracy and speed analyses consistently indicate that ADHD is not associated with a deficit in recognizing basic emotions. That is, their emotion identification accuracy was equivalent to the Non-ADHD group, and their small magnitude impairment on the speed of identifying emotions was more parsimoniously explained by their generally slower response times on choice-response tasks. Interestingly, adding concurrent working memory demands reduced speed but not accuracy for both groups. The relatively slower response times for emotion compared to animal identification in the low working memory condition, as well as the differential slowing of response times for animal vs. emotion identification when working memory demands increased, indicate that working memory is implicated in the speed at which children can recognize basic emotions (relative to the more automatic recognition of common animal names).

Discussion

The current study was the first to experimentally evaluate the presence/absence of, and a potential mechanism underlying, emotion recognition deficits in children with ADHD. The data provide decisive evidence that our manipulations of emotion recognition and working memory were successful, with large changes in speed and accuracy between affective and non-affective stimuli (Pérez-Edgar & Fox, 2003), medium changes in response speed between low and high working memory conditions (Conway et al., 2005), and interactions between the emotion and working memory manipulations that significantly affected response speeds. Additional strengths of the experiment include the fully-crossed experimental design, inclusion of a carefully phenotyped sample of children with and without ADHD matched for the number of non-ADHD clinical disorders (Wilens et al., 2002), and the omnibus findings that the ADHD group demonstrated reduced working memory capacity and slower response speeds relative to the Non-ADHD group as expected (Kasper et al., 2012; Karalunas et al., 2014). The results of this study suggest equivalent facial affect identification abilities among youth with and without ADHD, and that working memory is involved in the recognition of basic emotions in children, particularly as it relates to the speed with which children can identify emotions based on affective facial expressions.

First, we predicted that children with ADHD would make more errors and respond more slowly on choice-response tasks (i.e., emotion and non-emotion recognition tasks) than children without ADHD. This hypothesis was partially supported. Specifically, we found evidence that children with ADHD required more time to recognize and respond to stimuli than the Non-ADHD group, but the groups were equivalent in their accuracy. These results are consistent with overall slower response times on choice-response tasks for children with ADHD relative to comparison peers (Kofler et al., 2013). Of primary interest in the current study was the extent to which ADHD is associated with a unique deficit in emotion recognition that cannot be explained more parsimoniously by their general impairments on choice-response tasks (i.e., significant group × condition interaction; Kofler et al., 2013). With regard to accuracy, there was significant evidence *against* both the main effect of group and the group × condition interaction, indicating that children with ADHD are equivalent to children without ADHD in their ability to accurately identify both animals and emotions. In other words, emotion recognition abilities appear to be intact in pediatric ADHD, at least in the current carefully-phenotyped sample of school-aged children.

Second, we predicted that adding concurrent working memory demands would disrupt facial affect recognition accuracy/speed, and that this manipulation would disproportionately affect the ADHD group due to their well-documented working memory impairments (Kasper et al., 2012). This hypothesis was partially supported as well. We found that adding concurrent working memory demands disrupted facial affect recognition speed, not accuracy; however, unlike our hypothesis, this phenomenon comparably affected both groups, not just those with ADHD. Specifically, the condition × working memory interaction with response time as the dependent variable was significant, indicating that children were significantly faster at identifying animals than emotions under low working memory demands, but this difference was minimized when working memory was taxed. In other words, working memory was likely already involved in the identification of facial affect, while the introduction of working memory demands to the animal recognition task slowed response times to be more similar to children's baseline emotion recognition speed. This pattern suggests that working memory is likely implicated in basic emotion identification (Graziano & Garcia, 2016), whereas the identification of common animals is more automatic and less reliant on top-down neurocognitive processes (Shiffrin & Schneider, 1977).

Taken together, the accuracy and speed analyses described above are consistent in indicating that pediatric ADHD is not associated with a deficit in recognizing basic emotions. In fact, the evidence indicates that children with and without ADHD are *equivalent* in their ability to identify emotions during high working memory conditions that may more closely parallel the high top-down processing demands associated with *in vivo* social situations. Social interactions, while ubiquitous in children's daily lives, are complex neurocognitive tasks that require children to quickly process and respond to social bids, keep track of multiple conversation lines, integrate multiple sets of verbal/nonverbal communications, prepare a response using prior experience and knowledge of the rules for socially acceptable behavior in that specific setting, and hold that response until it is socially appropriate to respond (i.e., high working memory demands; Aduen et al., 2018). Moreover, our results were consistent with previous research documenting that children with ADHD are slower at information processing in general, including during choice-response tasks (Karalunas & Huang-Pollock, 2013; Kofler et al., 2013), rather than less efficient in emotional processing specifically. In sum, between-group differences in the present study were related to task demands that were independent of emotional stimuli. Laboratory tasks, including choice-response tasks, impose cognitive demands that often extend beyond the specific mechanism(s) of interest. For instance, choice-response tasks require attention to task stimuli, working memory (e.g., maintenance of task instructions, in vivo performance monitoring), and accurate/rapid decision-making. Importantly, individuals with ADHD demonstrate performance deficits on a wide variety of laboratory tasks, and they often show impaired ability to anticipate stimuli, prepare responses, rapidly process stimuli, and hold task instructions in mind (Hervey et al., 2004; Martinussen et al., 2005; Willcutt et al., 2005). Failure to account for broader deficits in task performance may lead to erroneous conclusions that ADHD is associated with emotion recognition deficits. Finally, adding concurrent working memory demands reduced speed but not accuracy for both groups, suggesting that working memory may be part of a mechanistic chain of processes that underlie children's ability to efficiently infer emotional state based on facial expression (Dickstein & Castellanos, 2011). Overall, findings from our carefully controlled experimental methodology lend support to the hypothesis that basic emotion recognition is intact in children with ADHD.

Limitations

The unique contribution of the current study was its fully-crossed manipulation of both emotional content and working memory demands to elucidate the presence/absence of, and a mechanism underlying, emotion recognition deficits in ADHD. Several caveats warrant consideration when interpreting results despite these and other study strengths (e.g., Bayesian statistics, control for comorbidities). First, it is possible that the slowed responding during the high vs. low working memory conditions was due to children actively rehearsing the to-be-recalled stimuli rather than engaging in the processing of the current animal/emotion. This possibility is rendered unlikely, however, by the strong condition × working memory interaction. That is, this slowing occurred disproportionately during the animal task, providing clear evidence that processing facial expressions to deduce affect is more reliant on higher-order control processes (demands on which produced slower responses even before adding additional top-down demands). Second, there is often a trade-off between careful laboratory control and ecological validity. The extent to which our findings generalize to “real world” settings or vary as a function of pubertal status (Lawrence, Campbell, & Skuse, 2015) is unknown, and further research on emotion detection in more dynamic and realistic circumstances is needed. Third, our experiment controlled for but does not indicate why children with ADHD showed impairments in basic choice-response tasks regardless of stimuli content. The underlying mechanisms that produce choice-response task difficulties in ADHD remain unclear, with emerging but mixed evidence and theoretical accounts implicating lower-level information processing efficiency (Karalunas & Huang-Pollock, 2013), higher-order impairments in working memory (Wiemers & Redick, 2017), impaired error monitoring (Shiels & Hawk, 2010), and/or overt inattentive and impulsive behavior during testing, among other explanations (for review see Kofler et al., 2013). Clarifying the nature of inconsistent choice-response task performance in ADHD remains an important avenue for future research, with implications for etiological models of ADHD and identification of novel intervention targets (Chacko et al., 2014).

Our use of animal pictures in the control conditions provided improved control for task-specific demands (e.g., matching in terms of number of discrete categories, image size, and use of high-quality photographs of biological entities across conditions) and stimuli familiarity (Eimas & Quinn, 1994). At the same time, other studies have used nonbiological control stimuli (e.g., geometric shapes; Hariri, Mattay et al., 2002; Hariri, Tessitore et al., 2002) based in part on evidence of overlapping, albeit moderately weaker, neural activation in response to animal and human faces that may reflect the inclusion of both face-specific and object-general neurons in face-responsive occipitotemporal regions (Chao, Martin, & Haxby, 1999; Haxby, Hoffman, & Gobbini, 2000). In the context of the current study’s findings that the animal and emotion tasks elicited differences in both accuracy and response times, it seems reasonable to argue that our use of animal pictures provided improved control for isolating effects specific to emotional processing of human faces. However, this conclusion remains speculative, and future studies may care to include nonbiological objects (Greif et al., 2006), obscure the animals’ faces (Haxby et al., 2000), use more ambiguous control stimuli, and/or include a variety of control stimulus categories to assess the veracity of the current findings.

Given that co-occurring conditions are common in ADHD (Wilens et al., 2002), inclusion of children with these comorbidities was important to maximize external validity and generalizability of our findings. We attempted to balance external and internal validity threats by recruiting a Non-ADHD group matched for the number of these Non-ADHD disorders; however, controlling for the number of other disorders does not perfectly equate the groups, and it is possible that these disorders affect emotion recognition in ways that contributed to the overall finding of intact emotion recognition in ADHD. Alternatively, it may be that previous findings of impaired emotion recognition in ADHD are more parsimoniously attributable to uncontrolled and/or unidentified comorbidities in those samples. Independent replication of our methodology with ‘pure’ ADHD and neurotypical samples would clarify how well equating groups for the number of Non-ADHD disorders maximizes external validity while maintaining internal validity.

Finally, the ADHD working memory deficit (d=0.56) was smaller in magnitude than expected (Kasper et al., 2012), and indeed appreciably smaller than estimates of working memory deficits obtained for this sample using a combination of spatial and phonological reordering tasks (e.g., *d*=1.22–1.45 in Kofler et al., in press). Although there is some evidence that spatial memory is more impaired than verbal memory in ADHD (Martinussen et al., 2005; but see Kasper et al., 2012), it may be that spatial tasks more reliably evoke central executive demands due to task parameters that interrupt spatial rehearsal by requiring visual saccades (Awh & Jonides, 2001; Postle et al., 2004). A more likely explanation may be that the dual-processing demands evoked by the current study's complex span tasks are less impaired in children with ADHD than the related but separable working memory processes of serial/temporal reordering and/or continuous updating (Wager & Smith, 2003). To our knowledge, only one study has simultaneously investigated all three of these working memory sub-processes in children with ADHD (Wells et al., in press), but the extent to which dual-processing, continuous updating, and serial/temporal reordering processes are differentially impaired in ADHD remains unknown because that study did not include a Non-ADHD comparison group.

Clinical Implications and Future Directions

Overall, our study indicates that ADHD is not associated with impaired emotion recognition but rather inconsistent performance on choice-response tasks that gives the appearance of emotion recognition deficits when more general information processing deficits are not controlled. These findings suggest that we need to examine alternate hypotheses to explain the well-documented impairments in social skills and emotion regulation associated with ADHD (Bunford, Evans, & Wymbs, 2015; DuPaul et al., 2001; Huang-Pollock et al., 2009; McConaughy et al., 2011; Walcott & Landau, 2004). The current study suggests that working memory may be implicated in emotion detection, and by extension perhaps social skills more generally (Kofler et al., 2018), as it significantly reduced emotion processing efficiency. The results also suggest the need to assess both working memory and information processing to understand top-down and bottom-up effects on emotion recognition (Ochsner et al., 2009). Future directions include determining whether emotion recognition deficits are detectable in more ambiguous situations (Hess et al., 1997) or when affect must be inferred from context rather than from direct evidence of facial expression (e.g., Barrett et al., 2007, 2011; Da Fonseca et al., 2009). In addition, the current study focused on the ability to identify emotions in others. Further research is needed to determine the ability of children with ADHD to identify their own emotions, their emotional reactivity to others' affect (Pietromonaco & Barrett, 2009), and the mechanisms associated with their difficulty regulating these emotions (Dixon-Gordon et al., 2015; Graziano & Garcia, 2016; Seymour et al., 2012; Walcott & Landau, 2004).

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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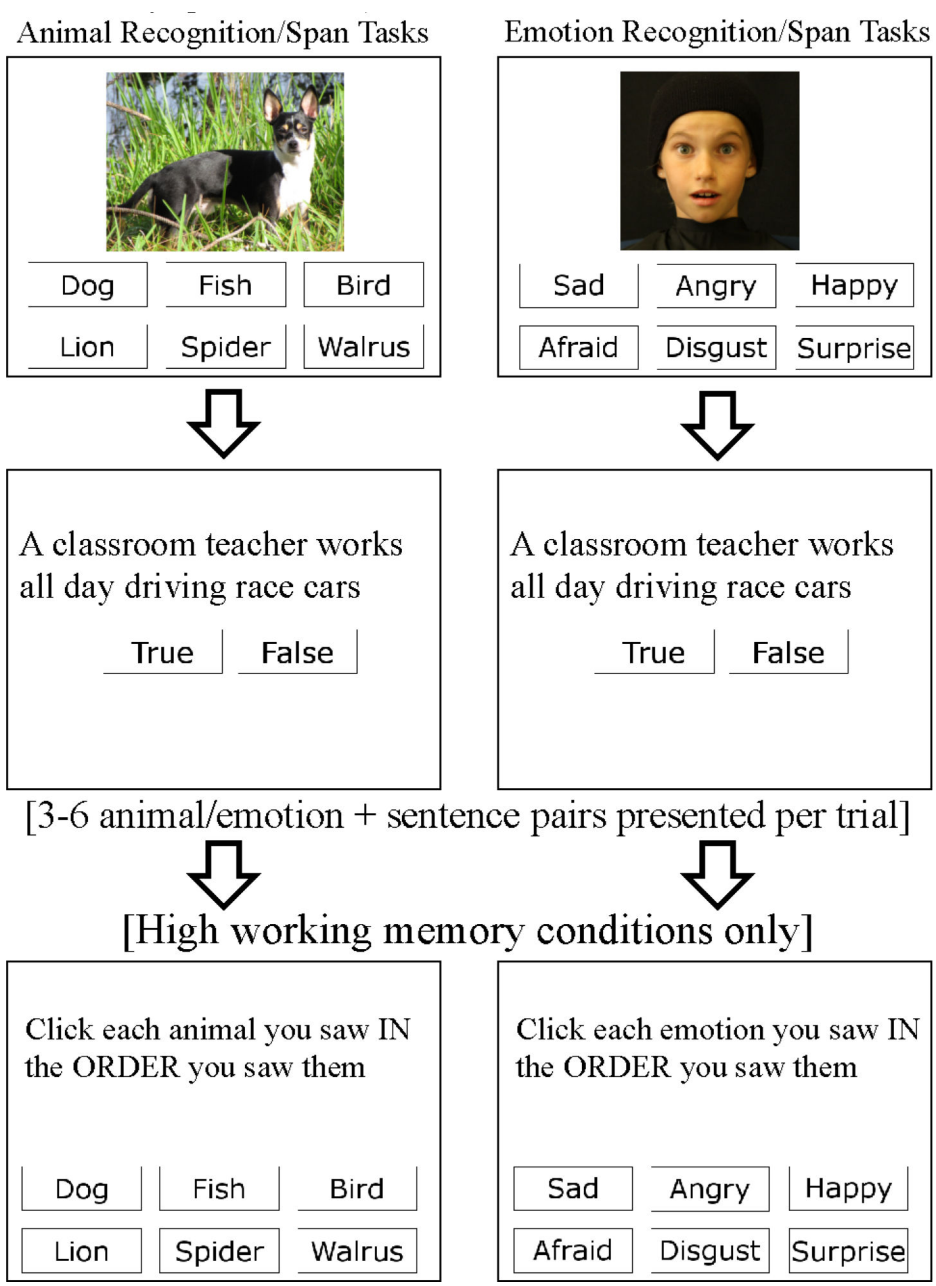

Figure 1.

Facial affect (emotion) and animal identification tasks. Each of the four counterbalanced tasks presented 36 randomly selected emotions/animals and sentences. Each low/high working memory trial pair (emotion identification/emotion span, animal identification/animal span) was identical except for the omission or addition of concurrent working memory demands. Words/icons outside the six large boxes were not shown on screen, but are included here to illustrate differences across the four experimental task variants. The parent of the child model provided written informed consent for publication of their child's photographs (used under license from the Dartmouth Database of Children's Faces; Dalrymple et al., 2013).

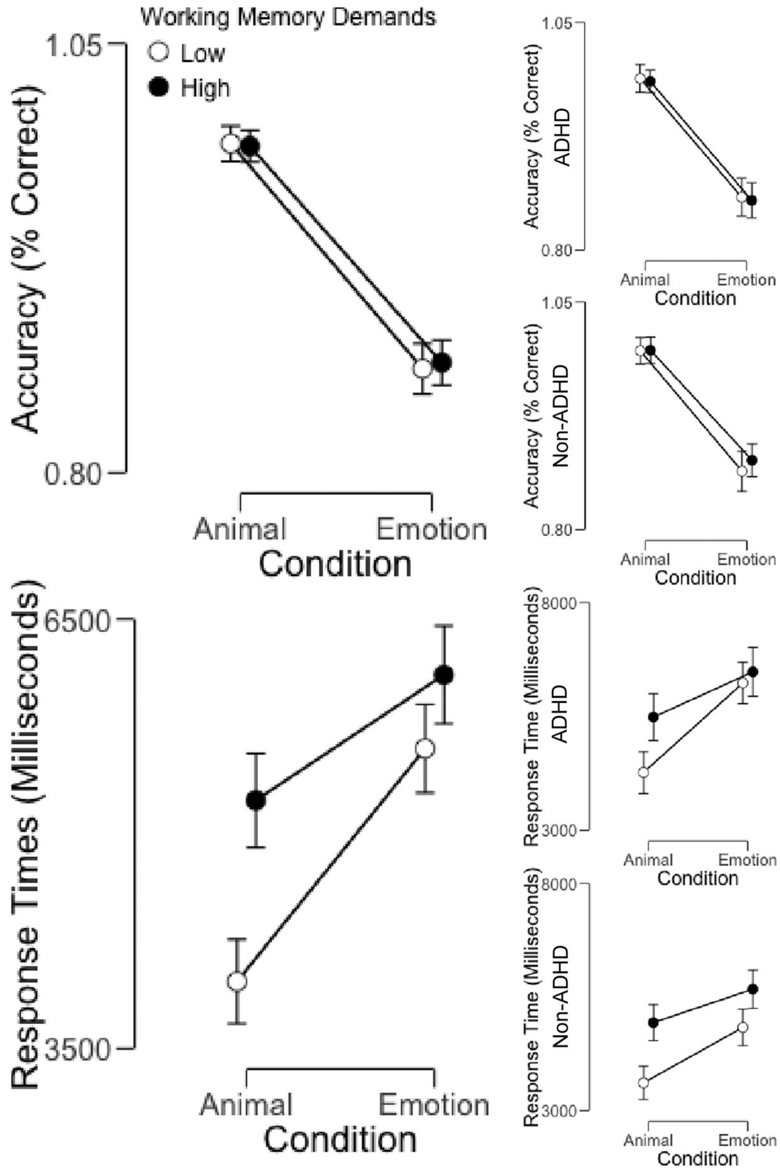

Figure 2.

Emotion and animal recognition accuracy (top) and speed (bottom) as a function of concurrent working memory demands (low, high). Error bars reflect Bayesian 95% credibility intervals. Insets reflect performance separately for the ADHD (top) and Non-ADHD groups (bottom).

Table 1.

Sample and demographic variables.

Variable	ADHD *M*	ADHD *SD*	Non-ADHD *M*	Non-ADHD *SD*	Cohen's *d*	BF_{10}	BF_{01}
N (Boys/Girls)	35 (22/13)		29 (16/13)		--		*2.77*
Age	10.29	1.59	10.58	1.54	0.18		3.12
SES	45.66	11.80	51.98	10.89	0.56	1.90	
Caregiver Education (frequencies)					--	--	1.56
Some high school	0		1				
High school graduate	7		1				
Some college	6		2				
College graduate	17		16				
Professional degree	5		9				
WISC-V VCI	103.91	14.19	110.00	14.10	0.43		1.14
Task Accuracy Data (percent correct)							
Animal Recognition	0.988	0.019	0.996	0.010	0.51	1.44	
Emotion Recognition	0.858	0.075	0.864	0.079	0.08		3.74
Animal Span	0.985	0.025	0.997	0.010	0.61	2.85	
Emotion Span	0.854	0.075	0.876	0.067	0.30		2.11
Task Response Time Data (milliseconds)							
Animal Recognition	4264.44	1330.61	3612.27	696.70	0.60	2.67	
Emotion Recognition	6229.71	2050.24	4830.96	992.96	0.84	24.08	
Animal Span	5479.89	2149.00	4937.63	1681.4	0.28		2.33
Emotion Span	6474.67	2246.38	5672.24	1873.9	0.39		1.46
Working Memory Recall (z-scores based on stimuli correct per trial)							
Omnibus (combined across tasks)	−0.25	1.05	0.30	0.86	0.56	3.88	
Animal Span	−0.22	1.05	0.26	0.88	0.49	2.48	
Emotion Span	−0.22	1.10	0.27	0.80	0.50	2.59	

Note. BF = Bayes Factor. SES = socioeconomic status; VCI = WISC-V Verbal Comprehension Index (IQ; standard scores).