Article

Journal of Attention Disorders
1–14

DOI: 10.1177/1087054719864636
journals.sagepub.com/home/jad
SAGE

Emotion Regulation and Children With Attention-Deficit/Hyperactivity Disorder: The Effect of Varying Phonological Working Memory Demands

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Abstract

Objective: Findings from extant studies of the relationship between ADHD-related emotion regulation and working memory deficits have been equivocal, and their correlational designs preclude inferences about the functional relationship between working memory demands and emotion regulation. This study aimed to experimentally examine the functional relationship between varying working memory demands and ADHD-related emotion regulation deficits. **Method:** Overt emotion regulation behaviors were coded while children with and without ADHD completed experimental tasks that manipulated low and high working memory demands. **Results:** Compared with typically developing children, children with ADHD exhibited large-magnitude overall emotion expression deficits, disproportionately greater self-criticism during high working memory conditions, and disproportionately greater positive emotion expression during low working memory demand conditions. **Conclusion:** These findings suggest that working memory demands are functionally related to emotion regulation deficits exhibited by children with ADHD and may explicate variability of emotion regulation difficulties related to environmental demands. (*J. of Att. Dis. XXXX; XX(X) XX-XX*)

Keywords

ADHD, emotional regulation, working memory

ADHD is a complex, highly heritable, and lifelong disorder that is characterized by symptoms of inattention, impulsivity, and hyperactivity (American Psychiatric Association [APA], 2013; Barkley, 2006). Prevalence of ADHD within the United States is approximately 7% (Thomas, Sanders, Doust, Beller, & Glasziou, 2015), and an average of US$36 billion is spent on the disorder each year (Erskine et al., 2014). Moreover, children with ADHD are at a higher risk for comorbid behavior and/or mood disorders (Jensen, Martin, & Cantwell, 1997), learning disorders (Daley & Birchwood, 2009), physical injury (Barkley, 2006), peer rejection (Hoza et al., 2005), and impairments in regulating emotions (Graziano & Garcia, 2016).

Emotion regulation is the ability to generate and maintain an emotion, as well as the ability to decrease an emotion's intensity and/or frequency (Cole, Michel, & O'Donnell, 1994; Gross, 1998). Emotion regulation is related to the development and refinement of executive functions, such as inhibition, planning, and working memory (Hofmann, Schmeichel, & Baddeley, 2012). Across the life span, children use inhibition to downregulate their emotions, based on social norms (e.g., Gross, 2002; Thompson, 1994), and use working memory to interpret co-occurring or complex emotions by recognizing emotional expressions, considering the context of a situation, and deciding how to modulate their own responses (e.g., Ochsner & Gross, 2005; Schmeichel, 2007). Furthermore, the complex, reciprocal nature of emotion and cognition suggests that an overlap in neural networks may contribute to this reciprocity in typically developing (TD) and psychiatric populations (e.g., Jin & Maren, 2015; Northoff et al., 2004; Phelps, 2004; Tyng, Amin, Saad, & Malik, 2017).

A recent meta-analytic review found that children with ADHD, compared with TD children, exhibit large-magnitude emotion regulation deficits ($d = .80$) that persist when controlling for the presence of cognitive functioning (Graziano & Garcia, 2016). The meta-analysis examined four areas of commonly identified deficits among children

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with ADHD, including (a) emotion recognition/understanding, (b) emotional reactivity/negativity/lability, (c) emotion regulation, and (d) empathy/callous-unemotional traits. Covert emotion regulation reflects internal processes to regulate a wide range of emotions that are typically measured with self-report, whereas overt behavior captured via behavioral observations likely falls within the emotional reactivity or emotion regulation categories of the meta-analysis. Although emotional reactivity and emotion regulation are moderately to strongly correlated (e.g., Derryberry & Rothbart, 1988; Eisenberg et al., 1993), they are distinct constructs such that emotional reactivity typically refers to a frequent onset of and/or rapid changes in emotions (Cole et al., 1994; Graziano & Garcia, 2016), whereas emotion regulation refers to a broader range of processes that include self-regulating emotions' expression, intensity, and duration to obtain a goal (Thompson, 1994, 2011)

Etiological causes of ADHD-related emotion regulation difficulties are unclear, but several ADHD models suggest that other neurocognitive deficits, such as working memory, underlie emotion regulation difficulties. For example, Barkley's (1997) inhibition model of ADHD suggests that working memory and self-regulation of affect are secondary to inhibition impairments. Walcott and Landau's (2004) findings, however, indicate that behavioral disinhibition is a weak predictor of ADHD-related emotion regulation deficits, and suggest that other executive functions may serve as stronger candidate features of the disorder's primary (i.e., inattention and hyperactivity/impulsivity) and tertiary (e.g., self-regulation impairments) symptoms (e.g., Berlin, Bohlin, Nyberg, & Janols, 2004). In Rapport et al.'s (2008) functional working memory model, working memory is suggested to underlie secondary deficits of ADHD. Research has suggested working memory is causally related to increased motor activity (Rapport et al., 2009) and underlies *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.; *DSM-5*; APA, 2013)–defined core symptoms, such as inattention (Kofler, Rapport, Bolden, Sarver, & Raiker, 2010), impulsivity/disinhibition (Alderson, Rapport, Hudec, Sarver, & Kofler, 2010; Patros, Alderson, Hudec, Tarle, & Lea, 2017; Tarle, Alderson, Patros, Arrington, & Roberts, 2019), social problems (Kofler et al., 2011), and academic underachievement (Rogers, Hwang, Toplak, Weiss, & Tannock, 2011). It stands to reason, therefore, that ADHD-related working memory deficits might also underlie emotion regulation difficulties. Indeed, findings from basic cognitive research suggest that working memory assists with decoding emotions (Phillips, Channon, Tunstall, Hedenstrom, & Lyons, 2008), emotional responding (Schmeichel, Volokhov, & Demaree, 2008), and distraction from negative moods (Van Dillen & Koole, 2007). Moreover, a recently proposed cognitive model suggests that domain-specific components of working memory (i.e., a maintenance subsystem or episodic buffer specialized for emotions) serve to maintain emotion-related information (Mikels, Reuter-Lorenz, Beyer, & Fredrickson, 2008).

To date, few studies have examined the relationship between working memory and emotion regulation in children with ADHD, and findings have been relatively equivocal. For example, Sjöwall, Backman, and Thorell (2015) and Berlin et al. (2004) identified working memory and emotion regulation as significant predictors of unique variance associated with ADHD symptoms and group membership, respectively. In contrast, Sjöwall, Sjöwall, Roth, Lindqvist, and Thorell (2013) found emotion regulation, but not working memory, predicted group membership. Finally, Wåhlstedt, Thorell, and Bohlin's (2008) study utilized a nonclinical sample and longitudinal design, and found that ADHD symptoms, but not executive functioning, affected problems with emotion regulation at a 2-year follow-up.

Inferences from previous studies about the relationship between ADHD-related working memory and emotion regulation deficits may be incomplete due to several methodological limitations. First, previous studies utilized measures of working memory, such as digit span backward (Sjöwall et al., 2015; Sjöwall et al., 2013; Wåhlstedt et al., 2008) and forward span visual-spatial tasks (Wåhlstedt et al., 2008) that at best provide metrics of storage/rehearsal processes and place low demands on the *working* component of working memory (i.e., central executive processes; Moleiro et al., 2013). To that end, the null association between working memory and emotion regulation found in Wåhlstedt and colleagues' (2008) study is not surprising as findings from recent meta-analytic (Kasper, Alderson, & Hudec, 2012; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005) and experimental (e.g., Tarle et al., 2017) studies suggest that central executive processes appear to be the most impaired component of working memory in children with ADHD.

Previous studies are also limited due to their reliance on rating scale measures of emotion regulation that may be confounded by variance associated with disruptive behavioral disorders, given the inherent overlap/similarity in rating scale items that target both constructs (e.g., *Does the child exhibit temper tantrums or irritability?* Bunford, Evans, & Wymbs, 2015; Graziano & Garcia, 2016). While emotion regulation deficits associated with ADHD and behavioral disorders share a similar phenotype to some degree, the etiology of behavioral disorders is typically due to inconsistent discipline and defiance rather than emotion regulation deficits (Bunford et al., 2015), whereas ADHD-related emotion regulation deficits may be due to executive dysfunction. Ratings scales may also be inherently vulnerable to rater bias and error in retrospective recall of children's behavior, as Sjöwall and Thorell (2019) found that teacher reports on ratings scales, relative to laboratory-based measures, overestimated deficits of emotion regulation and other executive functions.

Observational/behavioral coding is a promising alternative approach that minimizes many limitations associated with rating scales by directly measuring real-time changes in children's emotion regulation behaviors (Bunford et al., 2015). Although behavioral observations cannot measure internal-affective states, measurement of children's overt behaviors is expected to provide insight into internal-covert processes and overt behaviors that are most frequently observed by others. Relatively few studies of emotion regulation deficits in children with ADHD, however, have used observational coding in lieu of rating scales. Collectively, findings from these studies provide evidence that observational/behavioral coding methodology yields reliable and valid indices of emotion dysregulation that correlate with peer problems, maladaptive social behavior (Sjöwall & Thorell, 2019), chronic aggression, delinquency, and inattention (Hill, Degnan, Calkins, & Keane, 2006), and are predictive of social performance and knowledge of social status (Maedgen & Carlson, 2000; Melnick & Hinshaw, 2000).

A secondary benefit of observational/behavioral coding is the ability to observe real-time changes in behavior that covary with manipulated variables, which in turn establishes temporal precedence and allows for inferences about the functional relationship between variables. To that end, the current study combines observational coding with methodology derived from the dual process theory of cognition (Barrett, Tugade, & Engle, 2004). Specifically, the dual process theory suggests that neurocognitive processes such as working memory are limited resources that become depleted under conditions of high working memory demands. Furthermore, performance metrics of other nonworking memory processes evince declines to the extent that they are downstream of working memory and/or there is a bottleneck of available resources (Baddeley, 2003; Rohrer & Pashler, 2003). Children who complete a high-demand working memory task, for example, are expected to have fewer available working memory resources that may be allocated to regulate emotions.

The current study is the first to examine hypothesized etiological features of ADHD-related emotion regulation deficits by incorporating dual process theory and observational coding methodology. Specifically, variability in emotion regulation was observed and coded across counterbalanced tasks that systematically varied in working memory demands. Based on previous meta-analytic findings that identified large-magnitude emotion regulation (Graziano & Garcia, 2016) and working memory (Kasper et al., 2012) deficits in children with ADHD, the current study's sample of children with the disorder were expected to exhibit disproportionately greater emotion regulation deficits as working memory demands increased from low to high working memory demand conditions.

Method

Participants

Children between the ages of 8 and 12 years were recruited from flyers posted around the community, communication with local organizations (e.g., boy or girl scouts; parent–teacher organizations), mass emails to faculty and staff at the university, and a university-based mental health clinic. Prior to study participation, parents and children provided written consent and assent, respectively. Parents of all participating children were provided with full psychoeducational reports from the evaluation that included reliable and valid behavioral rating scales, cognitive and academic achievement assessments, behavioral observations, and clinical interviews.

Group assignment. Children were assigned to the ADHD or TD group based on a comprehensive diagnostic procedure that is consistent with the gold standard of identifying children with ADHD (Gualtieri & Johnson, 2005). Specifically, children and their parent(s)/guardian(s) completed an independently administered, semistructured clinical interview, the Kiddie-Schedule for Affective Disorders and Schizophrenia–Present and Lifetime Version (K-SADS-PL; Kaufman et al., 2016; Kaufman et al., 1997). Children's parents and teachers also completed standardized rating scales including the Child Behavior Checklist (CBCL; Achenbach & Rescorla, 2001), Teacher Report Form (TRF; Achenbach & Rescorla, 2001), and Conners-3 Parent and Teacher Ratings (C3P/T; Conners, 2008).

Children included in the ADHD group had (a) a diagnosis of ADHD by the directing psychologist based on *DSM-5* diagnostic criteria (APA, 2013), supported by information from the K-SADS-PL; (b) parent ratings that fell in the clinical range on the *DSM* ADHD subscale of the CBCL or C3P; and (c) teacher ratings that fell in the clinical range on the *DSM* ADHD subscale of the TRF or C3T. Of the 41 children who met the inclusion criteria in the ADHD group, 28 were diagnosed with ADHD Combined Presentation and 13 were diagnosed with ADHD Predominantly Inattentive Presentation. Twenty-eight children with ADHD also met criteria for at least one comorbid disorder, including oppositional defiant disorder (n = 14), specific learning disorder (n = 8), enuresis (n = 4), encopresis (n = 2), disruptive mood dysregulation disorder (n = 2), conduct disorder (n = 1), specific phobia (n = 1), persistent depressive disorder (dysthymia; n = 1), or major depressive disorder (n = 1). This rate of comorbidity is consistent with previous epidemiological studies (e.g., Busch et al., 2002) that suggest children with ADHD are commonly diagnosed with co-occurring mood, anxiety, behavior, elimination, and learning disorders. Six children with ADHD who were prescribed psychostimulant medication prior to participation were required to discontinue the use of medication 24 hr prior to all research sessions. Three children with ADHD were also prescribed nonstimulant medications (i.e., Paxil and Fluoxetine) prior to participation in the study.

Children in the TD group had (a) no clinical diagnosis based on the parent and child K-SADS-PL interviews and standardized rating scales (i.e., CBCL/TRF, and C3P/T); and (b) normal developmental history based on information provided by the parent during a psychosocial interview. A total of 35 children were included in the TD group.

Children presenting with (a) gross neurological, sensory, or motor impairment; (b) psychosis; (c) a history of a seizure disorder; or (d) a Wechsler Intelligence Scale for Children–IV or V (WISC-IV/WISC-V) Full-Scale IQ (FSIQ) score less than 80 were excluded from the study.

Measures

Phonological (PH) working memory task. The PH task (Alderson et al., 2015) measured PH working memory and was programmed using SuperLab Pro 4.5 software (Cedrus Corporation). The PH working memory task was developed based on Baddeley's (2003) multicomponent working memory model, and the task reflects the interaction between the central executive and PH storage/rehearsal processes. The PH task presented a series of shuffled numbers (i.e., ranging from 1 to 9) and one letter (e.g., T, G, A, or M) for each trial, similar to the WISC-V's Letter Number Sequencing task (Wechsler, 2014). However, the letter never appeared in the first or last position of the series, and stimuli were not presented twice in the same trial. The stimuli were delivered at a comfortable volume through computer speakers. A 200-ms interstimulus interval occurred after each number or letter was presented. Following each trial and stimulus presentation, an auditory click occurred before a green traffic light appeared on the screen, prompting children to make a verbal response. Children were instructed to rearrange and say the numbers in order from least to greatest and then say the letter last. Following verbal responses, children touched a touch-screen computer monitor (37 × 30 cm screen) to advance to the next trial.

Children were allotted a maximum of 10,000 ms per stimulus to respond (e.g., 40,000 ms for set-size 4) before the next trial started. The PH task was split into four blocks of varying set-sizes that correspond to the number of stimuli (3, 4, 5, and 6), and each set-size block consisted of 24 consecutive trials. The set-sizes were presented in a counterbalanced order to control for potential order effects. Prior to task administration, a block of five practice trials were administered before set-size 3 and again before set-sizes 4, 5, or 6 (depending on the counterbalanced order). Children were required to obtain an 80% or higher success rate during practice trials before beginning the experimental trials. Verbal responses were independently recorded by two coders situated behind a one-way mirror. Coders' responses were compared for interrater agreement. When discrepancies occurred, the responses were verified using video and audio recordings to remediate the disagreement. The average number of stimuli recalled correctly across set-sizes provided an estimate of working memory performance.

Control conditions. Children were instructed to draw or paint anything that they wanted for 5 min using the Microsoft Paint program. This condition places minimal demands on the temporary recall, rehearsal, or storage of information (i.e., working memory; Baddeley, 2007). Children completed two blocks of the control condition with one at the beginning (Control 1) and one at the end (Control 2) of each research session.

Emotion regulation coding. Adapted from previously established protocols (e.g., Melnick & Hinshaw, 2000), children's behavior and verbalizations were coded from videos of the children completing the PH task and control conditions using Noldus The Observer XT, Version 8 (Noldus Information Technology, 2008). Emotion regulation behaviors that were coded included *Self-Praise/Positive Self-Talk, Self-Criticism/Negative Self-Talk, Solicitations, Emotion Ventilation, Positive Emotion Expression, Shuts Down*, and *Total Emotion Expression* (see Table 1 for operational definitions and examples of each behavior). *Emotion Ventilation* was initially coded as Mild Emotion Ventilation and Intense Emotion Ventilation, but these codes were later combined due to the infrequency of intense emotion ventilation behaviors and the moderate correlation (r = .48) between mild and intense emotion ventilation. Behaviors were required to occur for a minimum of 1 s to be coded, and behaviors were not mutually exclusive. For example, a negatively toned expression such as "I am awful at this game" was coded as both Self-Criticism/Negative Self-Talk and Emotion Ventilation.

Two of the study's authors coded behaviors for multiple children and revised the coding definitions until 100% reliability was achieved. The coded videos were then used as a training video for other coders to practice and establish reliability. Each coder was required to reach at least 90% agreement with the lead researchers' videos for each task before proceeding to the coding of videos containing real data. To determine interrater agreement, two coders blind to children's diagnostic status coded 20% of randomly selected videos. Resulting kappa values ranged from 0.90 to 1.00 for self-praise, self-criticism, shuts down, solicitations, and emotion ventilation, and kappa values ranged from 0.85 to 1.00 for positive emotion expression.

Dependent variables were defined as the proportion of task time that children exhibited each behavior. Specifically, coders marked the start and stop times of target behaviors exhibited during a task, and the total duration of time a behavior was exhibited was then divided by the duration of

Table 1. Emotion Regulation Observational Codes.

Emotion regulation code	Emotion dysregulation domains/constructs	Behavioral indicators of code	Examples
Emotion ventilation	ERNL	Displays negative emotion through vocal or gestural medium, such as grunting, making a gesture of disappointment	Sighing, shaking his or her head, verbally acknowledging his or her frustration, phrases said in negative tones, postural changes (e.g., slumping down), slamming fists, yelling, or whining loudly
Positive emotion expression	ERNL	Displays positive, not neutral, emotional expression	Speaking in a positive tone, laughing, singing, or celebrating
Self-criticism/negative self-talk	ERNL	Any verbalizations directed negatively toward the self, his or her performance, or his or her mistakes	"I stink at this." "This is so hard." "Dang it. I got that wrong."
Self-praise/positive self-talk	EREG	Any verbalizations directed positively toward oneself or his or her performance, such as positive affirmation or encouragement	"I can do this!" "I'm good at this." "I got that one right!"
Shuts down	EREG	Disengages from the task demands, such as collapsing his or her body or crossing his or her arms and refusing to participate	Collapsing his or her body or crossing his or her arms and refusing to participate
Solicitations	EREG	Any verbal comment, including questions and complaints, directed toward the examiner	"Can I stop now?" "Can I start over?"
Total emotion expression	ERNL	The total duration of all emotion regulation variables that were observed above while accounting for overlapping codes	—

Note. Emotion regulation codes were not mutually exclusive. Emotion ventilation was coded as mild emotion ventilation and intense emotion ventilation, but these variables were combined due to low occurrence of intense emotion ventilation. Emotion regulation codes were adapted from Melnick and Hinshaw (2000), and the emotion dysregulation domains/constructs were described by Graziano and Garcia (2016). ERNL = emotional reactivity/negativity/lability; EREG = emotion regulation.

time required to complete the corresponding task. This procedure was repeated for each behavioral code across all tasks and yielded the percentage of time that the behaviors were observed at each condition (i.e., at each control condition or PH task set-size). Therefore, higher percentages reflect longer durations that each behavior was displayed, relative to the time it took to complete the task. For the Total Emotion Expression variable, the total duration of time any behavior was exhibited, while controlling for the overlap between variables, was examined after dividing by the duration of time required to complete the task. Finally, composite scores were computed by averaging across working memory conditions (i.e., set-sizes 3, 4, 5, and 6). Control 1 and Control 2 scores for each emotion regulation variable were averaged to create a control condition composite score.

Intellectual functioning. Children's current level of intellectual functioning was assessed using the WISC-IV (n = 58) or WISC-V (n = 17), depending on the version that was current at the time of the assessment. The WISC-IV and WISC-V were used to determine group inclusion (FSIQ > 80) and rule out the presence of an intellectual disability. Due to the strong association between working memory processes and FSIQ (Wechsler, 2003), controlling for FSIQ in subsequent analyses would remove variability associated with the study's independent variable. Consequently, following a procedure outlined by Alderson et al. (2010), an alternative estimate of FSIQ was created to reflect FSIQ with variance associated with working memory removed. Specifically, a regression-based procedure was conducted with PH composite as the independent variable and FSIQ as the dependent variable. The residual scores obtained from this procedure (i.e., $FSIQ_{residual}$) reflected FSIQ without variance associated with working memory and was used in preliminary analyses.

Procedure

Children completed cognitive and achievement assessments during two, 3-hr clinical sessions, while their parent(s) completed psychosocial and K-SADS-PL interviews. Clinical sessions were scheduled during weekday mornings to minimize potential fatigue from school or extracurricular activities that may affect children's performance. Children were administered the PH task and control conditions as part of a larger battery of counterbalanced experimental tasks that occurred during three, 3-hr research sessions. Research sessions were scheduled on Saturday mornings and/or early afternoons to minimize the number of school absences. Frequent breaks were taken after every two to three tasks to help reduce fatigue. Parents were provided with a copy of a comprehensive psychoeducational report during a feedback session to explain the results of the child's assessment.

Data Analytic Plan

All analyses were conducted using the Statistical Package for the Social Sciences (SPSS), Version 24 (IBM Corp., 2016). Tier 1 provided a preliminary examination of sample characteristics. Potential between-group differences in sample characteristics were examined as a first step using independent-samples *t* tests (age, socioeconomic status [SES], $FSIQ_{residual}$, and working memory performance) and Pearson's chi-square tests (ethnicity and gender) to determine whether covariate analyses were warranted. Data were transformed for Tier 2 by using the natural logarithm, $\ln(x + 1)$, due to excessive positive skewing associated with zero-inflated data. For Tier 2, seven 2 (ADHD, TD) × 2 (control composite, working memory composite) mixed-model analyses of variance (ANOVAs) were used to examine the potential interaction effects between group and condition on emotion regulation deficits (i.e., total emotion expression and individual codes). Significant interaction effects were probed using independent-samples *t* tests to examine between-group effects at each condition and repeated-measures ANOVAs to examine within-group effects. Main effects were interpreted for all nonsignificant interactions.

Results

Tier 1: Preliminary Analyses

Missing data. Eight children ($n_{ADHD} = 5$, $n_{TD} = 3$) were excluded due to hardware malfunctions. The final sample included 68 participants ($n_{ADHD} = 36$, $n_{TD} = 32$).

Power. G*Power (Faul, Erdfelder, Lang, & Buchner, 2007) was used to determine the sample size needed to detect within-group, between-group, and interaction effects across planned analyses. To estimate the power needed, a Cohen's *d* effect size of 0.80 was used based on the magnitude of ADHD-related emotion regulation deficits reported in a recent meta-analysis (Graziano & Garcia, 2016). Power was set to 0.80 based on Cohen's (1988) recommendations. For an effect size of 0.80, $\alpha = .05$, power = 0.80, two groups and two conditions (Control and Working Memory), 40 total participants were needed for a mixed-model ANOVA to detect an interaction, within-group effect, and between-group effect. The current study's final sample of 68 children suggested it was sufficiently powered.

Outliers. All variables were screened for univariate outliers prior to analyses. Outliers were defined as values at least 3.29 *SD*s (corresponding with a *p* value of .001) above or below the group's mean (Tabachnick & Fidell, 2001). Outliers were replaced with a value equal to ±3.29 *SD*s from the mean, dependent on the direction of the outlier. Eleven total emotion expression ($n_{ADHD} = 5$, $n_{TD} = 6$), 15 self-criticism ($n_{ADHD} = 11$, $n_{TD} = 4$), nine self-praise ($n_{ADHD} = 7$, $n_{TD} = 2$), nine shuts down ($n_{ADHD} = 7$, $n_{TD} = 2$), 15 solicitations ($n_{ADHD} = 13$, $n_{TD} = 2$), nine emotion ventilation ($n_{ADHD} = 5$, $n_{TD} = 4$), and 27 positive emotion expression ($n_{ADHD} = 22$, $n_{TD} = 5$) scores were identified as outliers.

Sample characteristics. The ADHD and TD groups did not differ based on gender, $\chi^2(1) = 0.23$, $p = .628$; age, $t(66) = 0.60$, $p = .549$, $d = 0.15$; Hollingshead (1975) SES,[1] $t(65) = 1.74$, $p = .087$, $d = 0.43$; ethnicity, $\chi^2(4) = 2.21$, $p = .697$; or $FSIQ_{residual}$,[2] $t(65) = 0.65$, $p = .519$, $d = 0.16$, and FSIQ scores of the ADHD ($M = 100.36$, $SD = 10.32$) and TD ($M = 107.23$, $SD = 13.39$) groups fell within the average range. As expected, the ADHD group exhibited poorer working memory performance compared with the TD group, $t(66) = 3.41$, $p = .001$, $d = 0.83$. Sample characteristics are summarized in Table 2.

Tier 2: Examination of Emotion Regulation Deficits and Increased Demands on Working Memory

Total emotion expression. A 2 (ADHD, TD) × 2 (control, working memory) mixed-model ANOVA examined the potential Group × Condition interaction effect on total emotion expression. The between-group main effect was significant, $F(1, 66) = 26.56$, $p < .001$, $\eta_p^2 = 0.29$, suggesting children with ADHD demonstrated significantly greater total emotion expression compared with TD peers. The main effect for condition was also significant, $F(1, 66) = 6.93$, $p = .011$, $\eta_p^2 = 0.10$, indicating that both groups of children displayed significantly higher total emotion expression for the working memory composite. The interaction was not significant, $F(1, 66) = 1.50$, $p = .225$, $\eta_p^2 = 0.02$ (see Table 3 and Supplementary Figure 1a).

Self-criticism. There was a significant interaction between group and condition on self-criticism, $F(1, 66) = 5.98$, $p = .017$, $\eta_p^2 = 0.08$. Post hoc independent-samples *t* tests were conducted to probe between-group differences within each condition. The ADHD group exhibited significantly

Table 2. Sample Characteristics Summary.

	TD (n = 32)	ADHD (n = 36)			
	M (SD)	M (SD)	χ^2	t	d
Ethnic composition			2.21		
Caucasian	78%	81%			
Native American	3%	8%			
Hispanic	3%	3%			
Asian	3%	0%			
Biracial	13%	8%			
Gender (% female)	13%	17%		−0.48	−0.12
Age	10.04 (1.46)	9.81 (1.69)		0.60	0.15
SES	50.41 (10.82)	46.09 (9.56)		1.74	0.43
$FSIQ_{residual}$	0.85 (10.80)	−0.73 (9.25)		0.65	0.16
WM performance	3.39 (0.73)	2.75 (0.81)		3.41**	0.83

Note. TD = typically developing; d = Cohen's d effect size; SES = Hollingshead socioeconomic status scores; $FSIQ_{residual}$ = Full-Scale IQ scores controlling for working memory performance; WM = working memory.
**p < .01.

more self-criticism than the TD group for the working memory composite, $t(42.24) = -2.91$, $p = .006$, $d = 0.69$, but the groups did not differ in self-criticism for the control composite, $t(66) = -0.94$, $p = .350$, $d = 0.24$. Two post hoc ANOVAs were completed to probe the within-group main effects in each group. The effect of condition was significant for both the TD group, $F(1, 31) = 5.14$, $p = .031$, $\eta_p^2 = 0.14$, and ADHD group, $F(1, 35) = 11.89$, $p = .001$, $\eta_p^2 = 0.25$. Collectively, compared with children in the TD group, children with ADHD exhibited disproportionately more self-criticism during the working memory composite compared with the control composite (see Table 3 and Supplementary Figure 1b).

Emotion ventilation. There was a significant main effect of group, $F(1, 66) = 12.93$, $p = .001$, $\eta_p^2 = 0.16$, indicating greater emotion ventilation by the ADHD group compared with the TD group. There was also a significant main effect of condition, $F(1, 66) = 55.05$, $p < .001$, $\eta_p^2 = 0.46$, with greater emotion ventilation for the working memory composite relative to the control composite by both groups. However, the interaction between group and condition on emotion ventilation was not significant, $F(1, 66) = 3.48$, $p = .067$, $\eta_p^2 = 0.05$ (see Table 3 and Supplementary Figure 1c).

Positive emotion expression. The interaction between group and condition on positive emotion expression was significant, $F(1, 66) = 13.22$, $p < .001$, $\eta_p^2 = 0.17$. Two post hoc independent-samples t tests were conducted to probe the between-group main effects for the interaction. The ADHD group exhibited significantly more positive emotion expression compared with the TD group on the control composite, $t(41.56) = -5.05$, $p < .001$, $d = 1.20$, and the working memory composite, $t(66) = -2.62$, $p = .011$, $d = 0.64$. Post hoc ANOVAs were conducted to examine the within-group main effects. The within-group effect was significant for the ADHD group, $F(1, 35) = 14.88$, $p < .001$, $\eta_p^2 = 0.30$, but not for the TD group, $F(1, 66) = 0.55$, $p = .46$, $\eta_p^2 = .017$ (see Table 3 and Supplementary Figure 1d).

Self-praise. The interaction effect, $F(1, 66) = 0.40$, $p = .530$, $\eta_p^2 = 0.01$, between-group main effect, $F(1, 66) = 1.09$, $p = .300$, $\eta_p^2 = 0.02$, and main effect for condition, $F(1, 66) = 0.52$, $p = .474$, $\eta_p^2 = 0.01$, were not significant (see Table 3 and Supplementary Figure 1e).

Shuts down. There was a significant main effect for condition, $F(1, 66) = 7.79$, $p = .007$, $\eta_p^2 = 0.11$, with more frequent shutting down for the working memory composite relative to the control composite. The interaction effect, $F(1, 66) = 3.56$, $p = .064$, $\eta_p^2 = 0.05$, and between-group main effect, $F(1, 66) = 3.56$, $p = .064$, $\eta_p^2 = 0.05$, were not significant (see Table 3 and Supplementary Figure 1f).

Solicitation. The ADHD group, compared with the TD group, exhibited more frequent solicitations with a significant between-group main effect, $F(1, 66) = 5.55$, $p = .021$, $\eta_p^2 = 0.08$. Neither the within-group main effect, $F(1, 66) = 3.76$, $p = .057$, $\eta_p^2 = 0.05$, nor the interaction effect, $F(1, 66) = 0.66$, $p = .421$, $\eta_p^2 = 0.01$, were significant (see Table 3 and Supplementary Figure 1g).

Discussion

Findings from previous studies (Berlin et al., 2004; Sjöwall et al., 2015; Sjöwall et al., 2013; Wåhlstedt et al., 2008) have been relatively equivocal with regard to the relationship between ADHD-related working memory and emotion

Table 3. Summary of ANOVA Results.

	TD	ADHD			
	M (*SD*)	*M* (*SD*)	*F*	*t*	*d*
Total emotion expression					
Control	0.23 (0.35)	1.25 (1.15)	—	—	1.20
WM condition	0.65 (0.62)	1.40 (0.93)	—	—	0.95
Between-group			26.56***		
Within-group			6.93*		
Group × Condition			1.50		
Self-criticism/negative self-talk					
Control	0.00 (0.00)	0.01 (0.36)	—	−0.94	0.24
WM condition	0.01 (0.28)	0.06 (0.09)	—	−2.91**	0.69
Between-group			7.51**		
Within-group			14.38***		
Group × Condition			5.98*		
ADHD post hoc			11.89**		
TD post hoc			5.14*		
Emotion ventilation					
Control	0.12 (0.22)	0.33 (0.43)	—	—	0.62
WM condition	0.49 (0.49)	0.95 (0.65)	—	—	0.81
Between-group			12.93**		
Within-group			55.05***		
Group × Condition			3.48		
Positive emotion expression					
Control	0.13 (0.29)	1.02 (1.01)	—	−5.05***	1.20
WM condition	0.19 (0.41)	0.46 (0.43)	—	−2.62*	0.64
Between-group			22.16***		
Within-group			8.93**		
Group × Condition			13.22***		
ADHD post hoc			14.88***		
TD post hoc			0.55		
Self-praise/positive self-talk					
Control	0.00 (0.00)	0.00 (0.01)	—	—	0.33
WM condition	0.00 (0.02)	0.00 (0.01)	—	—	0.06
Between-group			1.09		
Within-group			0.52		
Group × Condition			0.40		
Shuts down					
Control	0.00 (0.00)	0.00 (0.00)	—	—	0.00
WM condition	0.05 (0.21)	0.27 (0.62)	—	—	0.47
Between-group			3.56		
Within-group			7.79**		
Group × Condition			3.56		
Solicitations					
Control	0.00 (0.00)	0.02 (0.07)	—	—	0.47
WM Condition	0.01 (0.06)	0.05 (0.11)	—	—	0.47
Between-group			5.55*		
Within-group			3.76		
Group × Condition			0.66		

Note. Means reflect the percentage of time a behavior was exhibited. TD = typically developing; *d* = Cohen's *d* effect size; WM = working memory.
*$p < .05$. **$p < .01$. ***$p < .001$.

regulation deficits. These studies relied on measures that place few demands on the central executive component of working memory (i.e., forward and backward span tasks; Moleiro et al., 2013) and consequently do not tax working memory processes most impaired in children with ADHD (e.g., Kasper et al., 2012). Furthermore, previous studies have uniformly relied on emotion regulation rating scales that are likely to be confounded with comorbid disorders or global impairments (e.g., Bunford et al., 2015) and, at best, yield correlational findings that do not allow for inferences about the functional relationship between working memory demands and emotion regulation. The current study systematically varied working memory demands and observed corresponding changes in behaviorally coded emotion regulation exhibited by children with and without ADHD.

Overall, there was a large-magnitude, between-group difference in total emotion expression exhibited by children with ADHD and TD children, consistent with findings from previous meta-analytic (Graziano & Garcia, 2016) and experimental (e.g., Braaten & Rosén, 2000; Musser et al., 2011; Rosen & Factor, 2015) studies. Furthermore, greater total emotion expression was observed during high working memory demand conditions relative to low working memory control conditions. Generally, the significant relationship between total emotion expression and working memory aligns with findings from basic cognitive research that suggest a relationship between working memory and emotion regulation processes (e.g., Ochsner & Gross, 2005; Schmeichel, 2007).

The primary aim of the current study was to examine whether ADHD-related emotion regulation deficits are functionally related to varying demands on working memory. A priori, it was hypothesized that children with ADHD, compared with TD children, would exhibit a disproportionate increase in emotion dysregulation as working memory demands increased, and this disproportionate increase in emotion dysregulation would provide evidence of a functional relationship between ADHD-related working memory and emotion regulation deficits. Rationale for this hypothesis was derived from basic cognitive (Baddeley, 2003; Cowan, 2010) and social (e.g., Schmeichel & Demaree, 2010; Schmeichel et al., 2008) research that suggests working memory and self-regulation are limited resources that deplete with use. If working memory is involved in emotion regulation, one would expect increased emotion dysregulation during high working memory conditions due to fewer available resources (Baddeley, 2003; Schmeichel & Demaree, 2010). Moreover, relative to TD children, children with ADHD would be expected to exhibit disproportionate increases in emotion dysregulation due to large-magnitude impairments in working memory that are commonly characteristic of the disorder (Kasper et al., 2012; Rapport et al., 2008).

Indeed, both emotion ventilation and self-criticism increased for both groups as working memory demands were increased, and children with ADHD were identified as exhibiting greater emotion ventilation and self-criticism compared with TD children. These findings align with previous clinical research that suggest a majority of children with ADHD, but not all, exhibit greater emotional reactivity compared with TD peers (e.g., Anastopoulos et al., 2011). Most interesting was our finding that children in the ADHD group exhibited a disproportionate increase in self-criticism during the working memory condition, relative to the control condition. In light of previous findings that suggest negative responses (Melnick & Hinshaw, 2000) and working memory (Kofler et al., 2011) significantly predict social difficulties in children with ADHD, our finding of a relationship between self-criticism and working memory begins to evince a more complex, testable model where the relationship between working memory and ADHD-related social problems may be mediated by self-criticism. Of course, the directional relationship between these variables remains uncertain, particularly as previous research in healthy adults has demonstrated reciprocity of self-criticism affecting working memory performance and vice versa (e.g., Lueke & Skeel, 2017).

Children with ADHD, compared with TD children, also exhibited a disproportionate increase in positive emotion expression during low working memory demand conditions (i.e., control conditions). This finding may reflect elevated parasympathetic activity and overall greater levels of arousal (e.g., Musser et al., 2011); albeit, more research in this area is clearly needed before strong inferences are justified. Nevertheless, to some degree, these findings appear to provide divergent validity for our a priori hypothesis that emotion regulation deficits, and particularly increased negative emotions, would be greatest during conditions of high working memory demands. It is noted, however, that the disproportionately greater frequency of positive emotion expressions during control conditions might also reflect a deficit (e.g., Braaten & Rosén, 2000; Bunford et al., 2015; Maedgen & Carlson, 2000). For example, excessive laughing, singing, and/or celebrating may decrease controlled-focused attention, increase off-task behavior, and/or serve as a distraction to other children in a classroom setting. Furthermore, emotion regulation has been identified as a factor that can distinguish between psychological disorders (e.g., Southam-Gerow & Kendall, 2002), and dysregulation of positive emotions appears to be unique to the ADHD phenotype (Faraone et al., 2019).

Self-praise behaviors reflect a unique subset of positive emotion expressions that are distinct due to their egocentric characteristic. Surprisingly, self-praise behaviors did not differ between groups and did not significantly vary across conditions. Considered in isolation, these nonsignificant findings appear to contrast findings from previous research that suggest children with ADHD exhibit a positive illusory bias—the inflation of self-perception in comparison with actual performance (e.g., Hoza et al., 2004). The discrepancy between our findings and extant literature might be explained by the use of observational methods in the current study and open-ended questions and/or ratings scales in previous studies (e.g., Hoza et al., 2004; Hoza, Pelham, Waschbusch, Kipp, & Owens, 2001). Specifically, in contrast to the current study that observed and coded self-praise behaviors in real time during working memory and control tasks, previous studies of illusory bias in children with ADHD typically solicit children's attitudes and feelings about their performance a priori or post hoc of task completion (e.g., Hoza et al., 2001; Owens, Goldfine, Evangelista, Hoza, & Kaiser, 2007). Nevertheless, it is noted that the nonsignificant between-group difference in self-praise occurred in the context of a large-magnitude working memory performance deficit exhibited by children in the ADHD group. That is, compared with children in the TD group, children in the ADHD group performed worse but praised themselves similarly, consistent with what might be expected with a positive illusory bias. It is noted, however, that ADHD-related illusory biases might be better explained by deficient error monitoring (e.g., Geburek, Rist, Gediga, Stroux, & Pedersen, 2013). That is, children with ADHD may have deficits in monitoring their errors that appear to reflect an inflation of self-evaluation of their performance. Therefore, children in the ADHD group may have exhibited healthy levels of self-praise as a way of managing potential impacts of poor performance on their self-esteem.

Children in both groups exhibited more frequent shutting down during conditions with greater working memory demands. This finding appears to reflect expected increases in disengagement of children during more difficult and unstimulating tasks (Scime & Norvilitis, 2006). For example, shutting down behavior may be functionally related to behaviors such as learned helplessness (e.g., Overmier, 2002), withdrawal (e.g., Ladd, 2006), and/or avoidance (e.g., Huijding et al., 2009), which have been linked to decreased test performance (e.g., Firmin, Hwang, Copella, & Clark, 2004), negative expectations of later academic achievement (e.g., Valås, 2001), and psychological maladjustment (e.g., Eisenberg et al., 2001; Ladd, 2006; Valås, 2001).

Finally, children with ADHD exhibited more frequent solicitations compared with TD children. It is noted that our findings contrast previous findings that indicated boys with ADHD did not exhibit a greater number of solicitations during a frustration task (Melnick & Hinshaw, 2000) or classroom setting (Abikoff et al., 2002). One possible explanation for the discrepancy is that the relatively high percentage of solicitations observed in the current study resulted from high working memory demands imposed by the experimental tasks, whereas frustration tasks and classroom settings vary with respect to working memory demands. Alternatively, the current study's laboratory setting may have created an artificial environment that was more likely to elicit solicitations. For example, children who are reluctant to speak out in a classroom full of other children may feel more comfortable to engage in solicitation behavior in a controlled-isolated laboratory setting. Finally, parents who complete ratings scales and clinical interviews may misattribute their children's solicitation behavior as evidence of frustration, particularly in situations when working memory demands are high. This explanation is unlikely, however, given the current study's findings of ADHD-related emotion ventilation difficulties. Overall, our findings suggest that high working demands yield moderate-magnitude increases in solicitations from children with ADHD, which may serve multiple purposes that include attention seeking, escape behavior, and/or a distraction from aversive stimuli.

While the current study provides a unique examination of the functional relationship between ADHD-related emotion regulation deficits and demands on working memory, a few potential limitations warrant consideration. First, the ADHD group included children with comorbid disorders (e.g., oppositional defiant disorder, specific learning disorders, and elimination disorders), which may have confounded estimates of ADHD-related emotion regulation deficits and working memory (e.g., Pennington & Ozonoff, 1996). This rate of comorbidity, however, was expected based on past epidemiological findings (e.g., Busch et al., 2002), suggesting that the inclusion of comorbid disorders in our sample is likely to increase generalizability to the general population of children with ADHD. Moreover, a growing body of literature has found that emotion regulation deficits are likely due to deficits associated with ADHD and not comorbid conditions. For example, Seymour, Macatee, and Chronis-Tuscano (2016) found that the inclusion of comorbid behavioral disorders with ADHD did not moderate the magnitude of emotion regulation deficits. Furthermore, findings from cross-sectional (e.g., Anastopoulos et al., 2011) and longitudinal (e.g., Seymour, Chronis-Tuscano, Iwamoto, Kurdziel, & MacPherson, 2014) studies suggest that emotion regulation deficits mediate the relationships between ADHD symptoms and comorbid symptoms (e.g., anxiety and depression). This suggests that ADHD symptoms may predispose individuals with ADHD to greater likelihood of comorbid psychopathology, but the inclusion of comorbid disorders likely does not influence the observed emotion regulation deficits. Another potential limitation is the study's relatively low percentage of girls and its exclusive examination of PH working memory. Future research is needed to determine the extent to which these findings generalize to both males and females with the disorder, as well as other modalities (e.g., visuospatial) and components (e.g., simple recall and complex span tasks) of working memory. Finally, it is noted that children in both groups exhibited relatively low rates of emotional expression, as defined by our coding scheme. One possible explanation is that working memory demands are only weakly associated with variability in emotional regulation and/or other neurocognitive factors should be considered. Furthermore, it is noted that observational coding procedures only provide a metric of overt behavior that serves as an observable proxy of children's internal experience. It may be that children's overt expressions of emotions reflect momentary peaks of greater emotional reactivity that is unobservable. The extent to which behavioral codes of overt emotion expressions correlate with variability in children's covert-internal emotions may therefore be an interesting target for future studies.

Collectively, findings from this study suggest that variability in working memory demands is functionally related to the expression of disproportionate positive and negative emotions exhibited by children with ADHD, compared with TD peers, and add to a growing body of literature that suggests working memory underlies ADHD-related impairments, such as hyperactivity (Rapport et al., 2009), impulsivity (Patros et al., 2017), inattention (Kofler et al., 2010), disinhibition (e.g., Alderson et al., 2010), and social problems (Kofler et al., 2011). Moreover, these findings have strong translational value with respect to understanding specific emotion regulation deficits exhibited by children with ADHD and how variation in task- (e.g., homework vs. video games), environment- (e.g., school vs. play), and social- (e.g., formal vs. friends) related neurocognitive demands are functionally related to changes in ADHD-related emotional expression. As Faraone and colleagues (2019) recently suggested, *DSM-5* (APA, 2013) diagnostic criteria for ADHD describe impulsivity within the context of behaviors and cognitions but neglect to consider the context of emotions. Continued examination of ADHD-related emotion regulation deficits and associated underlying neurocognitive deficits is expected to advance the field's development and refinement of diagnostic criteria with improved accuracy, as well as novel treatment approaches that produce stable near- and far-transfer effects. For example, development of a well-validated and reliable standardized behavioral coding system may ultimately assist clinicians and researchers in distinguishing ADHD-related emotion dysregulation from symptoms associated with comorbid conditions and consequently improve diagnostic precision. Similarly, development of emotion regulation strategies that lessen the burden on working memory processes may improve affected children's ability to regulate emotions successfully and decrease associated impairment.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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Supplemental Material

Supplemental material for this article is available online.

Notes

1. Hollingshead socioeconomic status (SES) scores were not available for three participants due to insufficient information (e.g., missing parental education data).
2. One child was administered the Woodcock–Johnson Test of Cognitive Abilities–IV (Schrank, McGrew, & Mather, 2014), because the Wechsler Intelligence Scale for Children–V (WISC-V) was administered within the previous year. The score was not included in the between-group analysis.

References

Abikoff, H. B., Jensen, P. S., Arnold, L. L. E., Hoza, B., Hechtman, L., Pollack, S., . . . Wigal, T. (2002). Observed classroom behavior of children with ADHD: Relationship to gender and comorbidity. *Journal of Abnormal Child Psychology*, *30*, 349-359.

Achenbach, T. M., & Rescorla, L. A. (2001). *Manual for the ASEBA school-age forms and profiles*. Burlington: Research Center for Children, Youth, and Families, University of Vermont.

Alderson, R. M., Kasper, L. J., Patros, C. H. G., Hudec, K. L., Tarle, S. J., & Lea, S. E. (2015). Working memory deficits in boys with attention deficit/hyperactivity disorder (ADHD): An examination of orthographic coding and episodic buffer processes. *Child Neuropsychology*, *21*, 509-530. doi:10.1080/09297049.2014.917619

Alderson, R. M., Rapport, M. D., Hudec, K. L., Sarver, D. E., & Kofler, M. J. (2010). Competing core processes in attention-deficit/hyperactivity disorder (ADHD): Do working memory deficiencies underlie behavioral inhibition deficits? *Journal of Abnormal Child Psychology*, *38*, 497-507. doi:10.1007/s10802-010-9387-0

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Arlington, VA: American Psychiatric Publishing.

Anastopoulos, A. D., Smith, T. F., Garrett, M. E., Morrissey-Kane, E., Schatz, J. L., . . . Ashley-Kock, A. (2011). Self-regulation of emotion, functional impairment, and comorbidity among children with AD/HD. *Journal of Attention Disorders*, *15*, 583-592. doi:10.1177/1087054710370567

Baddeley, A. (2003). Working memory: Looking back and looking forward. *Nature Reviews Neuroscience*, *4*, 829-839. doi:10.1038/nrn1201

Baddeley, A. (2007). *Working memory, thought, and action*. New York, NY: Oxford University Press.

Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin*, *121*, 65-94.

Barkley, R. A. (2006). *Attention deficit hyperactivity disorder: Handbook for diagnosis and treatment* (3rd ed.). New York, NY: Guilford Press.

Barrett, L. F., Tugade, M. M., & Engle, R. W. (2004). Individual differences in working memory capacity and dual process theories of the mind. *Psychological Bulletin*, *130*, 553-573.

Berlin, L., Bohlin, G., Nyberg, L., & Janols, L.-O. (2004). How well do measures of inhibition and other executive functions discriminate between children with ADHD and controls. *Child Neuropsychology*, *10*, 1-13. doi:10.1076/chin.10.1.1.26243

Braaten, E. B., & Rosén, L. A. (2000). Self-regulation of affect in attention deficit-hyperactivity disorder (ADHD) and non-ADHD boys: Differences in empathic responding. *Journal of Counseling and Clinical Psychology*, *68*, 313-321. doi:10.1037//0022-006X.68.x.313

Bunford, N., Evans, S. W., & Wymbs, F. (2015). ADHD and emotion dysregulation among children and adolescents. *Clinical Child and Family Psychology Review*, *18*, 185-217.

Busch, B., Biederman, J., Cohen, L. G., Sayer, J. M., Monuteaux, M. C., Mick, E., . . . Faraone, S. V. (2002). Correlates of ADHD among children in pediatric and psychiatric clinics. *Psychiatric Services*, *53*, 1103-1111. doi:10.1176/appi.ps.53.9.1103

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum.

Cole, P. M., Michel, M. K., & O'Donnell Teti, L. (1994). The development of emotion regulation: Biological and behavioral considerations. *Monographs of the Society for Research in Child Development*, *59*, 73-100.

Conners, K. C. (2008). *Conners third edition (Conners 3)* [Manual]. Los Angeles, CA: Western Psychological Services.

Cowan, N. (2010). The magical mystery four: How is working memory capacity limited, and why? *Current Directions in Psychological Science*, *19*, 51-57.

Daley, D., & Birchwood, J. (2009). ADHD and academic performance: Why does ADHD impact on academic performance and what can be done to support ADHD children in the classroom? *Child: Care, Health, and Development*, *36*, 455-464.

Derryberry, D., & Rothbart, M. K. (1988). Arousal, affect, and attention as components of temperament. *Journal of Personality and Social Psychology*, *55*, 958-966.

Eisenberg, N., Cumberland, A., Spinrad, T. L., Fabes, R. A., Shepard, S. A., . . . Guthrie, I. K. (2001). The relations of regulation and emotionality to children's externalizing and internalizing problem behavior. *Child Development*, *72*, 1112-1134.

Eisenberg, N., Fabes, R. A., Bernzweig, J., Karbon, M., Poulin, R., & Hanish, L. (1993). The relations of emotionality and regulation to preschoolers' social skills and sociometric status. *Child Development*, *64*, 1418-1438.

Erskine, H. E., Ferrari, A. J., Polanczyk, G. V., Moffitt, T. E., Murray, C. J. L., Vos, T., . . . Scott, J. G. (2014). The global burden of conduct disorder and attention-deficit/hyperactivity disorder in 2010. *Journal of Child Psychology and Psychiatry*, *55*, 328-336.

Faraone, S. V., Rostain, A. L., Blader, J., Busch, B., Childress, A. C., Connor, D. F., & Newcorn, J. H. (2019). Practitioner review: Emotional dysregulation in attention-deficit/hyperactivity disorder—Implications for clinical recognition and intervention. *The Journal of Child Psychology and Psychiatry*, *60*, 133-150.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavioral Research Methods*, *39*, 175-191.

Firmin, M. W., Hwang, C., Copella, M., & Clark, S. (2004). Learned helplessness: The effect of failure on test-taking. *Education*, *124*, 688-693.

Geburek, A. J., Rist, F., Gediga, G., Stroux, D., & Pedersen, A. (2013). Electrophysiological indices of error monitoring in juvenile and adult attention deficit hyperactivity disorder (ADHD)—A meta-analytic appraisal. *International Journal of Psychophysiology*, *87*, 349-362. doi:10.1016/j.ijpsycho.2012.08.006

Graziano, P. A., & Garcia, A. (2016). Attention-deficit hyperactivity disorder and children's emotion dysregulation: A meta-analysis. *Clinical Psychology Review*, *46*, 106-123.

Gross, J. J. (1998). The emerging field of emotion regulation: An integrative review. *Review of General Psychology*, *2*, 271-299. doi:10.1037/1089-2680.2.3.271

Gross, J. J. (2002). Emotion regulation: Affective, cognitive, and social consequences. *Psychophysiology*, *39*, 281-291. doi:10.1017.S0048577201393198

Gualtieri, C. T., & Johnson, L. G. (2005). ADHD: Is objective diagnosis possible? *Psychiatry (Edgmont)*, *2*(11), 44-53.

Hill, A. L., Degnan, K. A., Calkins, S. D., & Keane, S. P. (2006). Profiles of externalizing behavior problems for boys and girls across preschool: The roles of emotion regulation and inattention. *Developmental Psychology*, *42*, 913-928. doi:10.1037/0012-1649.42.5.913

Hofmann, W., Schmeichel, B. J., & Baddeley, A. D. (2012). Executive functions and self-regulation. *Trends in Cognitive Sciences*, *16*, 174-180. doi:10.1016/j.tics.2012.01.006

Hollingshead, A. A. (1975). *Four-factor index of social status*. New Haven, CT: Yale University.

Hoza, B., Gerdes, A. C., Hinshaw, S. P., Arnold, L. E., Pelham, W. E., Molina, B. S. G., . . . Odbert, C. (2004). Self-perceptions of competence in children with ADHD and comparison children. *Journal of Consulting and Clinical Psychology*, *72*, 382-391.

Hoza, B., Mrug, S., Gerdes, A. C., Hinshaw, S. P., Bukowski, W. M., Gold, J. A., . . . Arnold, L. E. (2005). What aspects of peer relationships are impaired in children with attention-deficit/hyperactivity disorder? *Journal of Consulting and Clinical Psychology*, *73*, 411-423. doi:10.1037/0022-006X.73.3.411

Hoza, B., Pelham, W. E., Waschbusch, D. A., Kipp, H., & Owens, J. S. (2001). Academic task persistence of normally achieving ADHD and control boys: Performance, self-evaluations, and attributions. *Journal of Consulting and Clinical Psychology*, *69*, 271-283.

Huijding, J., Field, A. P., De Houwer, J., Vandenbosch, K., Rinck, M., & van Oeveren, M. (2009). A behavioral route to dysfunctional representations: The effects of training approach or avoidance tendencies towards novel animals in children. *Behaviour Research and Therapy*, *47*, 471-477. doi:10.1016/j.brat.2009.02.011

IBM Corp. (2016). *IBM SPSS Statistics for Windows, Version 24.0*. Armonk, NY: Author.

Jensen, P. S., Martin, D., & Cantwell, D. P. (1997). Comorbidity in ADHD: Implication for research, practice, and DSM-V. *Journal of the American Academy of Child & Adolescent Psychiatry*, *36*, 1065-1079. doi:10.1097/00004583-199708000-00014

Jin, J., & Maren, S. (2015). Prefrontal-hippocampal interactions in memory and emotion. *Frontiers in Systems Neuroscience*, *9*, 1-8. doi:10.3389/fnsys.2015.00170

Kasper, L. J., Alderson, R. M., & Hudec, K. L. (2012). Moderators of working memory deficits in children with attention-deficit/hyperactivity disorder (ADHD): A meta-analytic review. *Clinical Psychology Review*, *32*, 605-617. doi:10.1016/j.cpr.2012.07.001

Kaufman, J., Birmaher, B., Axelson, D., Perepletchikova, F., Brent, D., & Ryan, N. (2016). Kiddie-Schedule for Affective Disorders and Schizophrenia for School-Age Children–Present and Lifetime Version, DSM-5. Western Psychiatric Institute and Yale University.

Kaufman, J., Birmaher, B., Brent, D., Rao, U., Flynn, C., Moreci, P., . . . Ryan, N. (1997). Schedule for Affective Disorders and Schizophrenia for School-Age Children–Present and Lifetime version (K-SADS-PL): Initial reliability and validity data. *Journal of the American Academy of Child & Adolescent Psychiatry*, *36*, 980-988.

Kofler, M. J., Rapport, M. D., Bolden, J., Sarver, D. E., & Raiker, J. S. (2010). ADHD and working memory: The impact of central executive deficits and exceeding storage/rehearsal capacity on observed inattentive behavior. *Journal of Abnormal Child Psychology*, *38*, 149-161.

Kofler, M. J., Rapport, M. D., Bolden, J., Sarver, D. E., Raiker, J. S., & Alderson, R. M. (2011). Working memory deficits and social problems in children with ADHD. *Journal of Abnormal Child Psychology*, *39*, 805-817. doi:10.1007/s10802-011-9492-8

Ladd, G. W. (2006). Peer rejection, aggressive or withdrawn behavior, and psychological maladjustment from ages 5 to 12: An examination of four predictive models. *Child Development*, *77*, 822-846.

Lueke, N., & Skeel, R. (2017). The effect of self-criticism on working memory in females following success and failure. *Personality and Individual Differences*, *111*, 318-323.

Maedgen, J. W., & Carlson, C. L. (2000). Social functioning and emotion regulation in the attention deficit hyperactivity disorder subtypes. *Journal of Clinical Child Psychology*, *29*, 30-42. doi:10.1207/S15374424jccp2901_4

Martinussen, R., Hayden, J., Hogg-Johnson, S., & Tannock, R. (2005). A meta-analysis of working memory impairments in children with attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child & Adolescent Psychiatry*, *44*, 377-384.

Melnick, S. M., & Hinshaw, S. P. (2000). Emotion regulation and parenting in AD/HD and comparison boys: Linkages with social behaviors and peer preference. *Journal of Abnormal Child Psychology*, *28*, 73-86. doi:10.1023/A:1005174102794

Mikels, J. A., Reuter-Lorenz, P. A., Beyer, J. A., & Fredrickson, B. L. (2008). Emotion and working memory: Evidence for domain-specific processes for affective maintenance. *Emotion*, *8*, 256-266. doi:10.1037/1528-3542.8.2.256

Moleiro, C., Madureira, S., Verdelho, A., Ferro, J. M., Poggesi, A., Chabriat, H., . . . Inzitari, D. (2013). Confirmatory factor analysis of the Neuropsychological Assessment Battery of the LADIS study: A longitudinal study. *Journal of Clinical and Experimental Neuropsychology*, *35*, 269-278. doi:10.1080/13803395.2013.770822

Musser, E. D., Backs, R. W., Schmitt, C. F., Ablow, J. C., Measelle, J. R., & Nigg, J. T. (2011). Emotion regulation via the autonomic nervous system in children with attention-deficit/hyperactivity disorder (ADHD). *Journal of Abnormal Child Psychology*, *39*, 841-852.

Noldus Information Technology. (2008). *The observer XT reference manual 8.0*. Wageningen, The Netherlands: Author.

Northoff, G., Heinzel, A., Bermpohl, F., Niese, R., Pfennig, A., Pascual-Leone, A., & Schlaug, G. (2004). Reciprocal modulation and attenuation in the prefrontal cortex: An fMRI study on emotional-cognitive interaction. *Human Brain Mapping*, *21*, 202-212. doi:10.1002/hbm.20002

Ochsner, K. N., & Gross, J. J. (2005). The cognitive control of emotion. *TRENDS in Cognitive Sciences*, *9*, 242-249. doi:10.1016/j.tics.2005.03.010

Overmier, J. B. (2002). On learned helplessness. *Integrative Physiological & Behavioral Science*, *37*, 4-8.

Owens, J. S., Goldfine, M. E., Evangelista, N. M., Hoza, B., & Kaiser, N. M. (2007). A critical review of self-perceptions and the positive illusory bias in children with ADHD. *Clinical Child and Family Psychology Review*, *10*, 335-351. doi:10.1007/s10567-007-0027-3

Patros, C. H. G., Alderson, R. M., Hudec, K. L., Tarle, S. J., & Lea, S. E. (2017). Hyperactivity in boys with attention-deficit/hyperactivity disorder: The influence of underlying visuospatial working memory and self-control processes. *Journal of Experimental Child Psychology*, *154*, 1-12. doi:10.1016/j.jecp.2016.09.008

Pennington, B. F., & Ozonoff, S. (1996). Executive functions and developmental psychopathology. *Journal of Child Psychology and Psychiatry*, *37*, 51-87.

Phelps, E. A. (2004). Human emotion and memory: Interactions of the amygdala and hippocampal complex. *Current Opinion in Neurobiology*, *14*, 198-202. doi:10.1016/j.conb.2004.03.015

Phillips, L. H., Channon, S., Tunstall, M., Hedenstrom, A., & Lyons, K. (2008). The role of working memory in decoding emotions. *Emotion*, *8*, 184-191.

Rapport, M. D., Alderson, R. M., Kofler, M. J., Sarver, D. E., Bolden, J., & Sims, V. (2008). Working memory deficit in boys with attention-deficit/hyperactivity disorder (ADHD): The contribution of the central executive and subsystem processes. *Journal of Abnormal Child Psychology*, *36*, 825-837. doi:10.1007/s10802-008-9215-y

Rapport, M. D., Bolden, J., Kofler, M. J., Sarver, D. E., Raiker, J. S., & Alderson, R. M. (2009). Hyperactivity in boys with attention-deficit/hyperactivity disorder (ADHD): A ubiquitous core symptom or manifestation of working memory deficits? *Journal of Abnormal Child Psychology*, *37*, 521-534. doi:10.1007/s10802-008-9287-8

Rogers, M., Hwang, H., Toplak, M., Weiss, M., & Tannock, R. (2011). Inattention, working memory, and academic achievement in adolescents referred for attention deficit/hyperactivity disorder (ADHD). *Child Neuropsychology*, *17*, 444-458.

Rohrer, D., & Pashler, H. E. (2003). Concurrent task effects on memory retrieval. *Psychonomic Bulletin & Review*, *10*, 96-103. doi:10.3758/BF03196472

Rosen, P. J., & Factor, P. I. (2015). Emotional impulsivity and behavioral difficulties among children with ADHD: An ecological momentary assessment study. *Journal of Attention Disorders*, *19*, 779-793. doi:10.1177/1087054712463064

Schmeichel, B. J. (2007). Attention control, memory updating, and emotion regulation temporarily reduce the capacity for executive control. *Journal of Experimental Psychology: General*, *136*, 241-255. doi:10.1037/0096-3445.136.2.241

Schmeichel, B. J., & Demaree, H. A. (2010). Working memory capacity and spontaneous emotion regulation: High capacity predicts self-enhancement in response to negative feedback. *Emotion*, *10*, 739-744. doi:10.1037/a0019355

Schmeichel, B. J., Volokhov, R. N., & Demaree, H. A. (2008). Working memory capacity and the self-regulation of emotional expression and experience. *Journal of Personality and Social Psychology*, *95*, 1526-1540. doi:10.1037/a0013345

Schrank, F. A., McGrew, K. S., & Mather, N. (2014). *Woodcock-Johnson IV Tests of cognitive abilities*. Rolling Meadows, IL: Riverside.

Scime, M., & Norvilitis, J. M. (2006). Task performance and response to frustration in children with attention deficit hyperactivity disorder. *Psychology in the Schools*, *43*, 377-386.

Seymour, K. E., Chronis-Tuscano, A., Iwamoto, D. K., Kurdziel, G., & MacPherson, L. (2014). Emotion regulation mediates the association between ADHD and depressive symptoms in a community sample of youth. *Journal of Abnormal Child Psychology*, *42*, 611-621.

Seymour, K. E., Macatee, R., & Chronis-Tuscano, A. (2016). Frustration tolerance in youth with ADHD. *Journal of Attention Disorders*. Advance online publication. doi:10.1177/1087054716653216

Sjöwall, D., Backman, A., & Thorell, L. B. (2015). Neuropsychological heterogeneity in preschool ADHD: Investigating the interplay between cognitive, affective, and motivation-based forms of regulation. *Journal of Abnormal Child Psychology*, *43*, 669-680.

Sjöwall, D., Roth, L., Lindqvist, S., & Thorell, L. B. (2013). Multiple deficits in ADHD: Executive dysfunction, delay aversion, reaction time variability, and emotional deficits. *Journal of Child Psychology and Psychiatry*, *54*, 619-627. doi:10.1111/jcpp.12006

Sjöwall, D., & Thorell, L. B. (2019). A critical appraisal of the role of neuropsychological deficits in preschool ADHD. *Child Neuropsychology: A Journal on Normal and Abnormal Development in Childhood and Adolescence*, *25*, 60-80. doi:10.1080/09297049.2017.1447096

Southam-Gerow, M. A., & Kendall, P. C. (2002). Emotion regulation and understanding: Implications for child psychopathology and therapy. *Clinical Psychology Review*, *22*, 189-222. doi:10.1016/S0272-7358(01)00087-3

SuperLab Pro 4.5 [Computer program]. San Pedro, CA: Cedrus Corporation.

Tabachnick, B. G., & Fidell, L. S. (2001). *Using multivariate statistics* (5th ed.). New York, NY: Person.

Tarle, S. J., Alderson, R. M., Patros, C. H. G., Arrington, E. F., & Roberts, D. K. (2019). Working memory and behavioral inhibition in children with attention-deficit/hyperactivity disorder (ADHD): An examination of varied central executive demands, construct overlap, and task impurity. *Child Neuropsychology*, *25*, 664-687. doi:10.1080/09297049.1519068

Tarle, S. J., Alderson, R. M., Patros, C. H. G., Lea, S. E., Hudec, K. L., & Arrington, E. F. (2017). Attention-deficit/hyperactivity disorder and phonological working memory: Methodological variability affects clinical and experimental performance metrics. *Neuropsychology*, *31*, 383-394. doi:10.1037/neu0000364

Thomas, R., Sanders, S., Doust, J., Beller, E., & Glasziou, P. (2015). Prevalence of attention-deficit/hyperactivity disorder: A systematic review and meta-analysis. *Pediatrics*, *135*, e994-1001. doi:10.1542/peds.2014-3482

Thompson, R. A. (1994). The development of emotion regulation: Biological and behavioral considerations. *Monographs of the Society for Research in Child Development*, *59*, 25-52.

Thompson, R. A. (2011). Emotion and emotion regulation: Two sides of the developing coin. *Emotion Review*, *3*, 53-61. doi:10.1177/1754073910380969

Tyng, C. M., Amin, H. U., Saad, M. N. M., & Malik, A. S. (2017). The influences of emotion on learning and memory. *Frontiers in Psychology*, *8*, 1-22. doi:10.3389/fpsyg.2017.01454

Valås, H. (2001). Learned helplessness and psychological adjustment: Effects of age, gender and academic achievement. *Scandinavian Journal of Educational Research*, *45*, 71-90.

Van Dillen, L. F., & Koole, S. L. (2007). Clearing the mind: A working memory model of distraction from negative mood. *Emotion*, *7*, 715-723. doi:10.1037/1528-3542.7.4.715

Wåhlstedt, C., Thorell, L. B., & Bohlin, G. (2008). ADHD symptoms and executive function and impairment: Early predictors of later behavioral problems. *Developmental Neuropsychology*, *33*, 160-178. doi:10.1080/87565640701884253

Walcott, C. M., & Landau, S. (2004). The relation between disinhibition and emotion regulation in boys with attention deficit hyperactivity disorder. *Journal of Clinical Child and Adolescent Psychiatry*, *33*, 772-782. doi:10.1207/s15374424jccp3304_12

Wechsler, D. (2003). *Wechsler Intelligence Scale for Children* (4th ed.). San Antonio, TX: Psychological Corporation.

Wechsler, D. (2014). *Wechsler Intelligence Scale for Children–Fifth Edition*. San Antonio, TX: NCS Pearson.

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