Journal of Abnormal Child Psychology (2020) 48:525–537
https://doi.org/10.1007/s10802-019-00612-8

An Examination of Relations Among Working Memory, ADHD Symptoms, and Emotion Regulation

Nicole B. Groves[1] · Michael J. Kofler[1] · Erica L. Wells[1] · Taylor N. Day[1] · Elizabeth S. M. Chan[1]

Abstract

Emotion regulation difficulties are present in many, if not most, children with attention-deficit/hyperactivity disorder (ADHD) and confer risk for a host of adverse outcomes. Little is known, however, regarding the neurocognitive and behavioral mechanisms that underlie these difficulties. A well-characterized, clinically evaluated sample of 145 children ages 8–13 years (*M* = 10.33, *SD* = 1.47; 55 girls; 69% White/non-Hispanic) were administered multiple, counterbalanced working memory tests and assessed for emotion dysregulation and ADHD symptoms via multiple-informant reports. Bias-corrected, bootstrapped conditional effects modeling indicated that underdeveloped working memory exerted significant direct effects on emotion regulation in all tested models as well as indirect effects on emotion regulation via parent-reported hyperactive/impulsive symptoms (95% CIs excluded zero). Interestingly, hyperactive/impulsive symptoms also predicted emotion dysregulation when controlling for the influence of working memory. Inattention failed to predict emotion regulation difficulties in all tested models (all 95% CIs included zero). This pattern of results replicated across parent and teacher models and were robust to control for mono-informant bias, age, and gender. These findings suggest that emotion dysregulation in ADHD reflects, in part, both a direct outcome of underdeveloped working memory and an affective outcome of hyperactive and/or impulsive symptomatology, both attributable to and independent of the role of underlying working memory deficits.

Keywords Emotion regulation · Working memory · ADHD · Hyperactivity · Impulsivity · Executive function

Attention-deficit/hyperactivity disorder (ADHD) is a heterogeneous neurodevelopmental disorder present in approximately 5% of school-aged children (Polanczyk et al. 2014) and characterized by impairing symptoms of inattention, hyperactivity, and/or impulsivity (American Psychiatric Association 2013). Difficulties with emotion regulation are also present in the majority of children with ADHD and predict a host of adverse near- and long-term outcomes (Graziano and Garcia 2016). Experimental and correlational findings in the cognitive literature implicate working memory as a key mechanism underlying the ability to regulate emotions and suppress outward expression of strong emotions (Schmeichel et al. 2008; Schweizer et al. 2013; Sperduti et al. 2017). Additionally, experimental and longitudinal evidence suggests that underdeveloped working memory may exert a directional, if not causal, role in ADHD inattention and hyperactive/impulsive symptom expression (Karalunas et al. 2017; Kofler et al. 2010; Rapport et al. 2009). To our knowledge, however, no study to date has examined the link among working memory deficits, ADHD symptoms, and emotion dysregulation in children with ADHD. The current study addresses this gap in the literature, and uses well-validated tests of working memory, multi-informant/multi-instrument indices of ADHD symptoms and emotion regulation, and bias-corrected conditional effects modeling to characterize the relations among working memory, ADHD symptoms, and emotion regulation in a large and carefully-phenotyped sample of children with and without ADHD.

Emotion Regulation and ADHD

Emotion regulation difficulties are common among children with ADHD, occurring at clinically significant levels in approximately 48%–54% of pediatric ADHD cases based on

---

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s10802-019-00612-8) contains supplementary material, which is available to authorized users.

✉ Michael J. Kofler
kofler@psy.fsu.edu

[1] Department of Psychology, Florida State University, 1107 W. Call Street, Tallahassee, FL 32306-4301, USA

converting meta-analytic effect sizes ($d = 0.80$–0.95; Graziano and Garcia 2016) into the proportion of population overlap (Zakzanis 2001). Broadly speaking, emotion regulation refers to one's physiological, experiential, and behavioral expressions of an emotion and the ability to modulate the speed and intensity of escalation and de-escalation of that emotion (Bunford et al. 2015; Zelkowitz and Cole 2016). While there are several factors that influence the subjective experience and behavioral expression of emotion (Gross 1998), emotion regulation is of particular interest in the current study given (a) meta-analytic evidence of large magnitude impairments in this process in children with ADHD and (b) the availability of standardized parent and teacher reports that provide quantitative data on the frequency and severity of children's emotion dysregulation (Graziano and Garcia 2016).

Although there is growing interest in characterizing the nature of emotion dysregulation in children with ADHD (e.g., Bunford et al. 2015; Graziano and Garcia 2016), there is a paucity of research investigating potential factors underlying these difficulties. Understanding the mechanisms and processes that underlie emotion dysregulation in ADHD is particularly important given evidence that these symptoms are resistant to current gold-standard treatments for ADHD, including pharmacological intervention (Galanter et al. 2003) and behavioral parent training (Waxmonsky et al. 2008). As such, understanding the etiology of emotion dysregulation in children with ADHD is imperative when considering secondary lines of treatment to address these difficulties. Further, difficulties with emotion regulation persist into adulthood for individuals with ADHD (Richard-Lepouriel et al. 2016) and predict academic impairment (Classi et al. 2012; Qian et al. 2016), higher rates of health care utilization (Classi et al. 2012), and higher daily parenting stress (Walerius et al. 2016) over and above the influence of core ADHD behavioral symptoms (Bunford et al. 2014). Importantly, emotion regulation difficulties appear to exist in children with ADHD above and beyond what would be expected from common comorbid diagnoses such as ODD, depression, or anxiety (e.g., Bunford et al. 2014). Rather, early emotion dysregulation associated with ADHD appears to predict the later development of these comorbid conditions (Steinberg and Drabick 2015).

Taken together, the evidence base at this time indicates that emotion dysregulation is an impairing feature of ADHD that does not respond to first-line ADHD treatments, and evidence-based treatments directly targeting emotion regulation are limited. This is problematic given that difficulties with emotion regulation portend risk for adverse outcomes across a broad range of academic, social, and clinical outcomes. At the same time, the mechanisms and processes underlying this risk remain poorly understood. As described below, we hypothesized that impaired working memory may be a factor that underlies emotion dysregulation in ADHD due to shared developmental and neurological processes (Banich et al. 2009; Brass et al. 2005; Miller 2000; Owen et al. 2005; Wager et al. 2008; Wolfe and Bell 2007). In the next section, we review the evidence implicating working memory deficits in ADHD's phenotypic expression, followed by a review of the current evidence base linking working memory and emotion regulation in the cognitive and developmental literatures.

Working Memory and ADHD

Working memory refers to the active, top-down manipulation of information held in short-term memory (Baddeley 2007), and includes interrelated functions of the mid-lateral prefrontal cortex and interconnected networks that involve supervisory attentional control, updating, processing, and reordering (Nee and Jonides 2013; Wager and Smith 2003). Recent investigations of executive functioning heterogeneity in ADHD suggest that approximately 62% to 85% of children with ADHD have working memory deficits when assessed using tasks with a prominent executive component (Karalunas et al. 2017; Kasper et al. 2012; Kofler et al. 2018a). Working memory is associated with the primary behavioral symptoms of ADHD, including inattention (Gathercole et al. 2008; Kofler et al. 2010), hyperactivity (Hudec et al. 2015; Rapport et al. 2009), and impulsivity (Raiker et al. 2012; Patros et al. 2015). Additionally, working memory abilities predict ADHD symptom severity in longitudinal studies (Halperin et al. 2008; Salari et al. 2017; van Lieshout et al. 2017). Improvements in working memory are also associated with ADHD symptom reduction longitudinally, while other cognitive processes implicated in ADHD (i.e., response inhibition, delayed reward discounting) do not appear to covary with ADHD symptoms over time (Karalunas et al. 2017). Importantly, experimentally manipulating working memory demands can elicit symptoms of ADHD, suggesting that these relations are not likely attributable to third variable, epiphenomenal, or other non-directional explanations (Kofler et al. 2010; Rapport et al. 2009). Finally, working memory deficits in ADHD have been linked with ecologically valid indices of impairment in functional domains that have also been linked with emotion regulation difficulties, including social problems (Bunford et al. 2014; Kofler et al. 2011) and academic underachievement (Rennie et al. 2014). Taken together with the cross-sectional and longitudinal findings, this line of research suggests that working memory deficits may be a potential causal pathway to ADHD-related inattentive and hyperactive/impulsive symptomology (Kofler et al. 2010; Rapport et al. 2009). To our knowledge, however, no study to date has assessed the extent to which underdeveloped working memory may impart risk for difficulty regulating emotions in children with ADHD.

Working Memory and Emotion Regulation

Executive functioning in general (Schmeichel and Tang 2015; Wante et al. 2017) and working memory in particular have been linked with emotion regulation in most (McRae et al. 2012; Opitz et al. 2014; Rutherford et al. 2016; Schweizer et al. 2011, 2013, 2017) but not all studies (Dubert et al. 2016; Gyurak et al. 2009, 2012; Marceau et al. 2018). Working memory's association with emotion regulation abilities has been documented in infants/toddlers (Wolfe and Bell 2007), adolescents (Schweizer et al. 2017) and adults (e.g., Schmeichel et al. 2008; Sperduti et al. 2017; Xiu et al. 2016) using a wide range of methodologies, including physiological markers (e.g., Sperduti et al. 2017), the ability to suppress facial expressions during experimental tasks (e.g., Schmeichel et al. 2008), and self-report and other-informant questionnaires (e.g., Rutherford et al. 2016). Emotion regulation also seems to rely on many of the same frontoparietal neural networks (Banich et al. 2009; Wager et al. 2008) that are involved in performance on working memory tasks (Brass et al. 2005; Miller 2000; Owen et al. 2005).

Evidence for a directional effect of working memory on emotion regulation, rather than vice versa, comes from experimental studies demonstrating that increased working memory load may interfere with emotion processing and regulation by reducing cortical activation in areas implicated in emotion processing, whereas increasing emotional salience of stimuli fails to interfere with working memory recall (Erk et al. 2007; Schmeichel et al. 2008; Van Dillen et al. 2009; cf. Gray et al., 2002; Spies et al., 1996). For example, Erk et al. (2007) found that cortical activity was significantly reduced in the amygdala and ventral striatum as working memory demands increased. Conversely, there was no interference effect of emotional stimuli on working memory task performance (Erk et al. 2007). Similarly, Van Dillen et al. (2009) found that adding a cognitively demanding task diminished amygdala responses after exposure to negative stimuli, suggesting that working memory load may mitigate emotional reactivity to negative stimuli by increasing activation in the right dorsolateral frontal cortex and the right superior parietal cortex. Additionally, Schmeichel et al. (2008) demonstrated that individual differences in working memory capacity are related to the ability to suppress the expression of experimentally-induced emotion. Specifically, participants with higher working memory capacity were better able to suppress their emotions when instructed, despite no differences in the subjective experience of emotional intensity relative to participants with lower working memory capacity (Schmeichel et al. 2008). Taken together, these studies suggest that working memory and emotion regulation are not only supported by overlapping neural networks, but that increasing working memory load diminishes activation in cortical regions associated with processing emotion and impacts the ability to regulate behavioral expressions of emotion.

Current Study

The evidence base at this time indicates that many, if not most, children with ADHD have impairments in working memory and emotion regulation. In addition, evidence from the developmental and cognitive literatures suggests that working memory may be a key mechanism underlying the ability to effectively regulate the expression of emotions. However, to our knowledge, the extent to which these findings may explain emotion regulation difficulties in children with ADHD has not been investigated. The current study is the first to examine the relation between working memory and the ability to regulate emotions in a carefully-phenotyped clinical child sample using a multi-trait, multi-method, and multi-informant approach to assess the unique and overlapping relations among working memory abilities, ADHD inattentive and hyperactive symptoms, and emotion regulation abilities. Bias-corrected, bootstrapped conditional effects modeling (Hayes 2013) was used to assess the extent to which working memory abilities predict better-developed emotion regulation abilities, both independently and via working memory's effects on ADHD inattentive and hyperactive/impulsive symptoms (e.g., Kofler et al. 2010). We hypothesized that better-developed working memory would predict better-developed emotion regulation skills. In addition, we expected this association to be partially attributable to working memory's relation with ADHD inattentive and hyperactive/impulsive symptoms, which in turn impact emotion regulation (i.e., both direct and indirect effects of working memory on emotion regulation).

Method

Participants

The sample comprised 145 children aged 8 to 13 years (*M* = 10.33, *SD* = 1.47; 55 girls) from the Southeastern U.S. recruited through community resources from 2013 to 2018 for participation in a larger study of the neurocognitive mechanisms underlying pediatric attention and behavioral problems. The Florida State University IRB approved the study prior to and throughout data collection, and all parents and children gave informed consent/assent. Sample ethnicity was mixed with 100 Caucasian/Non-Hispanic (69%), 18 Hispanic (12.4%), 13 African American (9%), 4 Asian (2.8%), and 10 multiracial children (6.9%; Table 1). All children spoke English.

Table 1 Sample and demographic variables

Variable	ADHD		Non-ADHD					
	M	*SD*	*M*	*SD*	Cohen's *d*	*t*	$\chi 2$	*p*
N (Boys/Girls)	102 (66/36)		43 (24/19)		–	–	1.02	.31, *ns*
Age	10.23	1.44	10.56	1.53	–	1.24	–	.22, *ns*
SES	48.51	11.72	49.79	12.04	–	0.60	–	.55, *ns*
VCI	105.07	16.88	108.84	11.96	–	1.33	–	.18, *ns*
Ethnicity (A, MR, B, H, W)	(1, 8, 9, 9, 75)		(3, 2, 4, 9, 25)		–	–	9.01	.06, *ns*
Working Memory Component Score	−0.33	0.93	0.79	0.64	−1.40	−8.32	–	<.001
Parent Emotion Regulation (Raw Score)	20.82	5.19	17.02	4.50	0.78	4.18	–	<.001
Teacher Emotion Regulation (Raw Score)	14.11	5.13	11.95	4.05	0.47	2.70	–	.02
Parent Attention Problems (Raw Score)	12.97	2.93	9.33	4.08	1.02	5.32	–	<.001
Teacher Attention Problems (Raw Score)	14.42	4.14	9.63	6.44	0.88	4.50	–	<.001
Parent Hyperactivity/Impulsivity (Raw Score)	16.27	6.25	9.58	4.93	1.19	6.25	–	<.001
Teacher Hyperactivity/Impulsivity (Raw Score)	13.43	8.44	7.56	7.88	0.72	3.90	–	<.001

Note: A = Asian; B = Black/African American; MR = Multiracial ; H = Hispanic; SES = Hollingshead SES total score; VCI = Wechsler Verbal Comprehension Index; W = White/Non-Hispanic

All children and caregivers completed a comprehensive evaluation that included detailed, semi-structured clinical interviewing and multiple norm-referenced parent and teacher questionnaires. A detailed account of the comprehensive psychoeducational evaluation can be found in the larger study's preregistration: https://osf.io/nvfer/. The final sample was composed of 145 children, including 49 children with ADHD; 53 children with ADHD and common comorbidities (22 anxiety, 10 depression, 14 oppositional-defiant disorder/ODD, and 29 suspected specific learning disorders); 21 with common clinical diagnoses but not ADHD (18 anxiety, 3 depression, 2 ODD, and 1 suspected specific learning disorder); and 22 neurotypical children (Table 1). Psychostimulants ($N_{prescribed} = 44$; 30.3%) were withheld ≥24 h for neurocognitive testing. Psychoeducational evaluations were provided to caregivers. Children were excluded if they presented with gross neurological, sensory, or motor impairment; non-stimulant medications that could not be withheld for testing; or history of seizure disorder, psychosis, intellectual disability, or autism spectrum disorder.

Procedure

Working memory testing occurred as part of a larger battery of neuropsychological testing that involved 1–2 sessions of approximately three hours each. All tasks were counterbalanced to minimize order effects. Children received brief breaks after each task and preset longer breaks every 2–3 tasks to minimize fatigue. Children were seated in a caster-wheel swivel chair. 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 and Sanson 1994).

Measures

Working Memory

The Rapport et al. (2009) computerized working memory tests correctly classify children with vs. without ADHD at similar rates to parent and teacher ADHD rating scales (Tarle et al. 2017), and predict hyperactivity (Rapport et al. 2009), inattention (Kofler et al. 2010), impulsivity (Raiker et al. 2012), and ADHD-related functional impairments (e.g., Kofler et al. 2018b). Reliability and validity evidence includes good to excellent internal consistency ($\alpha = 0.82–0.97$; Kofler et al. 2018b), 1–3-week test-retest reliability (0.76–0.90; Sarver et al. 2015), and expected relations with criterion working memory complex span ($r = 0.69$) and updating tasks ($r = 0.61$; Wells et al. 2018). Six trials per set size were administered in randomized/unpredictable order (3–6 stimuli/trial; 1 stimuli/s) as recommended (Kofler et al. 2016). Five practice trials were administered before each task (80% correct required). Task duration was approximately 5 (visuospatial) to 7 (phonological) minutes.

Phonological Working Memory Children were presented a series of jumbled numbers and a letter (1 stimuli/s). The letter was never presented first or last to minimize primacy/recency effects and was counterbalanced to appear equally in the other serial positions. Children reordered and recalled the numbers from least to greatest, and said the letter last (e.g., 4H62 is correctly recalled as 246H).

Visuospatial Working Memory Children were shown nine squares arranged in three offset vertical columns. A series of 2.5 cm dots were presented sequentially (1 stimuli/s); no two dots appeared in the same square on a given trial. All dots were black except one red dot that never appeared first or last to minimize primacy/recency effects. Children reordered the dot locations (black dots in serial order, red dot last) and responded on a modified keyboard.

Composite Working Memory Variable We controlled for task impurity (Conway et al. 2005) by selecting tasks that differed on short-term memory modality (phonological vs. visuospatial) and computing a Bartlett maximum likelihood weighted average based on the intercorrelations among scores at each set size (i.e., component score; DiStefano et al. 2009). This weighted average provides a more accurate estimate of construct stability than confirmatory approaches (Willoughby et al. 2016). Conceptually, this process improves construct specificity by removing variance from non-executive task demands, time-on-task effects (via inclusion of 4 blocks/task), short-term memory modality, and other non-shared task parameters (e.g., orthographic-to-phonological conversion; Alderson et al. 2015). Thus, the 8 working memory performance variables (4 blocks each for PHWM, VSWM) were reduced to a single working memory indicator (54.60% of variance explained; loadings = 0.46–0.82). The participant ($N = 145$) to component (1) ratio was acceptable (Hogarty et al. 2005). Higher scores reflect better working memory.

ADHD Symptoms

ADHD symptoms were assessed using parent and teacher total raw scores from the Behavior Assessment Scale for Children (BASC-2/3; Reynolds and Kamphaus 2015) Attention Problems and Hyperactivity subscales. Raw scores were used as recommended for research purposes (Achenbach, 1991). Psychometric support for these subscales includes high internal consistency ($\alpha = 0.79–0.94$), test-retest reliability ($r = 0.87–0.91$) and expected correspondence with other indices of ADHD symptoms (e.g., Achenbach and Rescorla 2001; Conners 2008; DuPaul et al. 2016). Higher scores indicate higher quantity/severity of ADHD symptoms.

Emotion Regulation

Emotion regulation was assessed using parent and teacher total raw scores from the Behavior Rating Inventory of Executive Function (BRIEF; Gioia et al. 2000) Emotional Control subscale. This subscale assesses parent and teacher perceptions of children's difficulties at modulating emotional responses (e.g., "mood changes frequently", "has explosive, angry outbursts"). Informants rate children on a three-point Likert scale (*never a problem, sometimes a problem, often a problem*). Evidence for the reliability and validity of the BRIEF Emotional Control subscale includes high internal consistency ($\alpha = 0.89–0.93$), 3-week test-retest reliability ($r = 0.79–0.92$) and expected relations with other parent- and teacher-reports of emotion regulation (e.g., Achenbach and Rescorla 2001; Conners 2008; Reynolds and Kamphaus 2015). Higher scores indicate more difficulty with emotion regulation.

Intellectual Functioning (IQ) and Socioeconomic Status (SES)

IQ was estimated using the Verbal Comprehension Index of the WISC-IV ($n = 2$), WASI-II ($n = 35$), or WISC-V ($n = 108$; Wechsler 2003, 2011, 2014). Hollingshead (1975) SES was estimated based on caregiver(s)' education and occupation.

Data Analysis Plan

The study's primary analyses used PROCESS (Hayes 2013) with 10,000 bootstrapped samples to analyze the bias-corrected relations among working memory, ADHD symptoms, and emotion dysregulation while covarying age and gender (Preacher et al. 2007). Bias-corrected, bootstrapped conditional effects modeling was preferred because it allowed shared variance among predictors to be parsed according to theory and previous research. Working memory performance was modeled as a predictor of inattentive symptoms, hyperactive/impulsive symptoms, and emotion dysregulation. The ADHD symptom clusters were also modeled as predictors of emotion dysregulation. Inattention and hyperactivity/impulsivity were included separately based on evidence that they differentially predict relations between working memory and other ADHD-related impairments (e.g., Bunford et al. 2014; Kofler et al. 2018b). To remove mono-informant bias, parent-reported ADHD symptoms were modeled to predict teacher-reported emotion dysregulation, and vice versa, in separate models. Sensitivity analyses were then conducted to probe the extent to which results were influenced by our control for age, gender, and mono-informant bias.

Importantly, the BASC-2/3 Attention Problems and Hyperactivity subscales were considered appropriate predictors because they do not contain any items that explicitly assess emotion regulation (Reynolds and Kamphaus 2015). Pathway directionality was specified a priori based on the available literature reviewed above. Specifically, working memory was modeled to predict ADHD symptoms, rather than vice versa, based on prior theoretical work and experimental evidence that increasing working memory demands evokes inattentive and hyperactive behavior (Kofler et al. 2010; Rapport et al. 2009), whereas working memory deficits remain large when covarying attentive behavior during testing (Kofler et al. 2010). In addition, ADHD symptoms were modeled as predictors of emotion dysregulation given conceptualizations of emotion regulation difficulties as secondary features of ADHD (Graziano and Garcia 2016). Finally, working memory was modeled as a predictor of emotion regulation, rather than vice versa, given the preponderance of evidence support effects in this direction (Erk et al. 2007; Schmeichel et al. 2008; Van Dillen et al. 2009; cf. Gray et al., 2002; Spies et al., 1996). Notably, the cross-sectional design precludes testing competing models regarding directional effects of working memory and emotion regulation or emotion regulation and ADHD symptoms (i.e., reversing arrows does not distinguish plausible models; Thoemmes 2015). Effects are considered statistically significant if their 95% confidence intervals (CIs) do not contain zero. Effect ratios for significant indirect effects indicate the proportion of the total effect (c pathway) that is conveyed via the indirect pathway (ab; i.e., effect ratio = ab/c). Raw scores for all variables were converted to z-scores based on the current sample to allow path coefficients to be interpreted as standardized β-weights (Preacher et al. 2007).

Results

Power Analysis

Large effects were predicted based on large relations between emotion regulation and ADHD symptoms ($d = 0.80–0.95$; Graziano and Garcia 2016) and large relations between working memory and ADHD symptoms ($d \geq 2.0$; Kasper et al. 2012). Our N of 145 exceeds the $N = 34$ required for bias-corrected bootstrapping to detect an effect of these expected magnitudes for $\alpha = 0.05$ and power = 0.80 with one intermediate effect (Fritz and MacKinnon 2007). Conservatively assuming partial mediation and approximately equal contributions of each mediator, $N = 100$ produced power = 0.94–0.96 to detect the total indirect effect with two intermediate effects (Briggs 2006). Power for detecting significance for each intermediate effect with $N = 100$ was 0.92–0.94. Thus, the current study's N of 145 is adequately powered to detect effects of the expected magnitude.

Preliminary Analyses

Each of the independent and dependent variables were screened for univariate outliers, defined as values greater than 2 interquartile ranges outside of the median. Seven data points (0.14% of data points from the ADHD group and 1.99% of data points from the Non-ADHD group) were identified as outliers and were corrected to the most extreme value within 2 interquartile ranges of the median. Data were screened for multivariate outliers (defined as SDBETA >1; Cook and Weisberg 1982). No multivariate outliers were identified. Missing data were determined to be missing completely at random (Little's MCAR test: $\chi^2 = 5.53$, $p = 0.79$) and were imputed using expectation maximization based on all available data. This process affected six (0.59%) data points. Task data from subsets of the current battery have been reported for subsets of the current sample to examine conceptually unrelated hypotheses in Kofler et al. (2018a-d). Data for the study's primary outcome, emotion dysregulation, have not been previously reported. Demographic characteristics are shown in Table 1. The zero-order correlation matrix is reported in Supplemental Table 1 (online). The models with parent- and teacher-reported emotion regulation as the outcome were run separately but are reported together for readability given the consistency across models.

Primary Analyses: Cross-Informant Conditional Effects Models

As shown in Fig. 1, results of the bias-corrected, bootstrapped conditional effects models covarying age and gender indicated that better-developed working memory was associated with better-developed emotion regulation based on both parent ($\beta = -0.20$, 95% CI = −0.37 to −0.03) and teacher report ($\beta = -0.17$, 95% CI = −0.35 to −0.0007). Better working memory abilities also predicted fewer parent-reported inattentive ($\beta = -0.34$, 95% CI = −0.51 to −0.17), parent-reported hyperactive/impulsive ($\beta = -0.25$, 95% CI = −0.41 to −0.08), and teacher-reported inattentive symptoms ($\beta = -0.28$, 95% CI = −0.45 to −0.11); the working memory-hyperactive/impulsive association did not reach significance based on teacher report ($\beta = -0.14$, 95% CI = −0.30 to 0.03). In addition, fewer hyperactivity/impulsivity symptoms, but not attention problems, predicted better-developed parent-reported ($\beta = 0.33$, 95% CI = 0.12 to 0.53) and teacher-reported emotion regulation ($\beta = 0.35$, 95% CI = 0.12 to 0.58) when controlling for working memory.

Conditional effects of working memory through cross-informant hyperactivity/impulsivity symptoms were significant when parent-reported hyperactivity/impulsivity was modeled to predict teacher-reported emotion regulation (indirect effect: $\beta = -0.09$, 95% CI = −0.19 to −0.02; ER = 0.53); this indirect effect did not reach significance when teacher-reported hyperactivity/impulsivity was modeled to predict parent-reported emotion regulation ($\beta = -0.04$, 95% CI = −0.11 to 0.006). The direct effect of working memory on teacher-reported emotion regulation was no longer significant after accounting for working memory's effects on emotion regulation via the hyperactivity/impulsivity pathway ($\beta = -0.13$, 95% CI = −0.31 to 0.05); the direct effect of working memory on parent-reported emotion regulation remained significant as expected based on the lack of significant indirect effects in that model (Fig. 1). No conditional effects via the attention problems pathway were observed (both 95%CIs include zero).

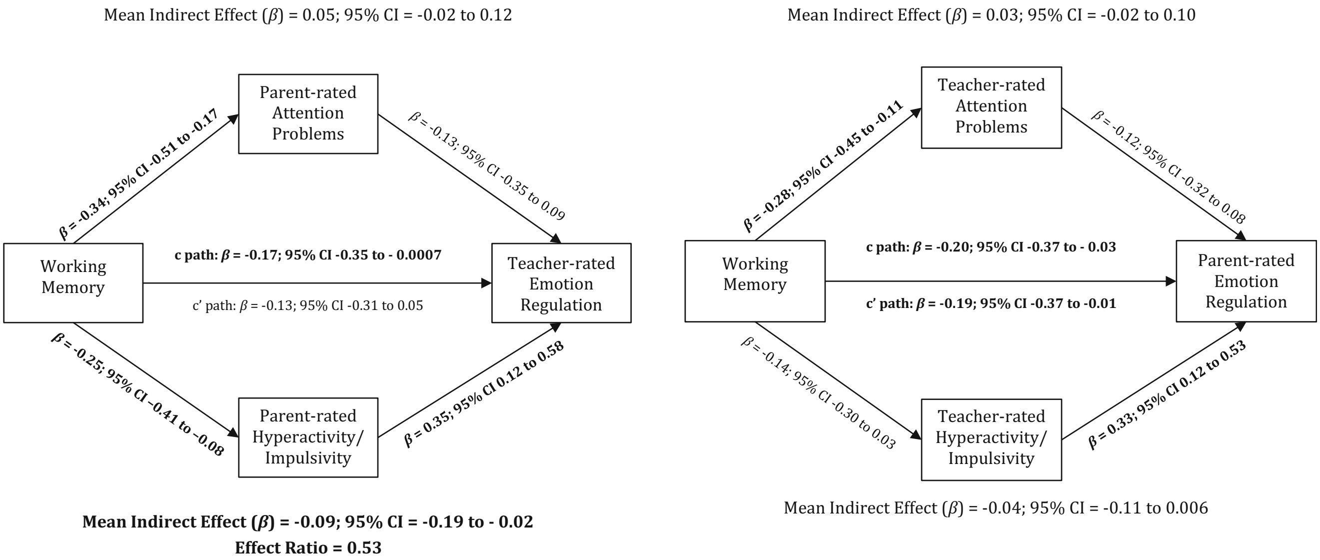

Fig. 1 Cross-informant conditional effects models with age and gender covaried. *Note:* Effects are significant if their 95% CIs do not contain zero (bolded)

Sensitivity Analyses

Additional analyses were conducted to probe the extent to which results were influenced by our a priori decisions to control for (a) age and gender by using these variables as covariates and (b) mono-informant bias via the use of cross-informant models. Results are reported in the Supplementary Online materials and summarized here. First, we repeated the primary analyses while removing the statistical control for age and gender. Next, we substituted the cross-informant for single-informant data (i.e., parent-reported ADHD symptoms predicting parent-reported emotion dysregulation, and teacher-reported ADHD symptoms predicting teacher-reported emotion dysregulation). As shown in Supplemental Figures 1 and 2, results in all cases were highly consistent with those reported above, including direct effects of working memory on emotion regulation, direct effects of hyperactivity/impulsivity on emotion regulation when controlling for working memory, indirect effects of working memory on emotion regulation via parent-reported hyperactivity/impulsivity, and no direct or indirect effects via the attention problems pathway (all 95% CIs include zero) in all models. In terms of effect ratios for the significant indirect effects of working memory on emotion regulation via the parent-reported hyperactivity/impulsivity pathway, the effect ratio of 0.53 reported above increased slightly when control for age and gender was relaxed (effect ratio = 0.58) and increased substantially when removing control for mono-informant bias (effect ratio = 0.95), highlighting the inflated effects associated with, and importance of controlling for, mono-informant bias.

Taken together, the cross-informant and mono-informant models were highly consistent in indicating that working memory predicted emotion regulation, and that hyperactivity/impulsivity predicted emotion regulation independent of working memory. Evidence for indirect effects of working memory on emotion regulation through hyperactivity/impulsivity was more nuanced, such that this effect was conveyed only via parent-reported hyperactivity/impulsivity, regardless of whether parent- or teacher-reported emotion regulation was the outcome. In other words, working memory predicts emotion regulation, and hyperactivity/impulsivity predicts emotion regulation both independently and potentially via its role as a phenotypic expression of working memory deficits that underlie the behavioral expression of ADHD symptoms. In contrast, there was no evidence to suggest a link between children's inattentive symptoms and their skill at regulating their emotions.

Discussion

The present study was among the first to examine the relations among working memory, ADHD symptoms, and children's skills at regulating their emotions. Additional strengths of the study include the use of a multi-method, multi-informant, and multi-task design, inclusion of a clinically-evaluated and carefully-phenotyped sample, and a direct replication of the study's findings across different informants/settings. Overall, the results were highly consistent across models, and indicated that working memory exerted significant direct effects on emotion regulation. The models diverged in terms of the extent to which this association was conveyed via working memory's association with ADHD hyperactive/impulsive symptoms. These findings were consistent with evidence from the cognitive literature suggesting a functional relation between working memory and emotion regulation (Schmeichel et al. 2008), recent evidence suggesting a relation between varying working memory demands and the frequency of emotional expression in children with ADHD (Tarle et al., 2019), and experimental evidence linking working memory with ADHD-related excess gross motor movement (hyperactivity; Kofler et al. 2015; Rapport et al. 2009) and impulsivity (Raiker et al. 2012). In addition, the results extend previous findings by demonstrating secondary effects of the working memory/hyperactivity relation onto children's skills at regulating their emotions and suggesting that working memory's effects on emotion regulation may occur both directly and via an indirect behavioral pathway. Interestingly, hyperactivity/impulsivity also predicted emotion regulation independent of working memory, whereas ADHD inattentive symptoms were not significantly associated with emotion regulation despite showing the expected covariation with working memory. These findings were consistent with meta-analytic evidence linking ADHD with emotion regulation difficulties (Christiansen et al. 2019; Graziano and Garcia 2016) and extend this line of inquiry by suggesting specificity in this relation such that this risk appears to be conveyed specifically via ADHD hyperactive/impulsive rather than inattentive symptoms.

Past literature suggests that deficits in working memory may underlie the phenotypic expression of ADHD-related inattentive and hyperactive/impulsive behaviors (e.g., Kofler et al. 2010; Rapport et al. 2009), and that emotion dysregulation is a common feature associated with ADHD (Christiansen et al. 2019; Graziano and Garcia 2016). The present study tested the hypothesis that working memory would predict ADHD symptoms which would, in turn, predict emotion regulation. We found partial support for this prediction, with indirect effects of working memory on emotion regulation through parent- but not teacher-reported hyperactive/impulsive symptoms. Given that this effect was replicated across cross-informant and mono-informant models, it appears that working memory may be further implicated in emotion dysregulation insofar as underdeveloped working memory contributes to the expression of ADHD-related hyperactive/impulsive symptoms as they are perceived by parents. That is, emotion regulation deficits in children with ADHD appear to reflect, in part, the behavioral expression of underlying working memory deficits that result in difficulty controlling impulses and/or regulating gross motor activity (e.g., Kofler et al. 2010; Rapport et al. 2009). This conclusion is consistent with mixed evidence suggesting that emotion dysregulation may be more prevalent in children with ADHD who present with higher levels of hyperactive/impulsive symptoms (for review, see Bunford et al. 2015).

Interestingly, hyperactivity/impulsivity also exerted direct effects on emotion regulation independent of the effects of working memory in all models tested, suggesting that there may be multiple pathways to emotion dysregulation in ADHD. That is, the current findings suggest at least four independent pathways through which children exhibit difficulties with emotion regulation: (1) emotion dysregulation that is directly related to working memory abilities; (2) emotion dysregulation that reflects the behavioral expression of underdeveloped working memory that results in age-unexpected difficulties controlling impulses (Raiker et al. 2012) and/or gross motor movements (Kofler et al. 2015; Rapport et al. 2009), as evidenced by the significant indirect effects observed in all models that included parent-reported hyperactivity/impulsivity; (3) emotion dysregulation secondary to additional aspects of the hyperactive/impulsive syndrome unrelated to underlying working memory deficits, as evidenced by the significant effects of hyperactivity/impulsivity on emotion regulation even after controlling for working memory; and (4) emotion dysregulation independent of all neurocognitive and behavioral mechanisms tested in the current study (inferred from the non-multicollinearity between emotion regulation and all assessed predictors). This multiple pathway hypothesis is consistent with evidence for the multidimensionality of working memory (Nee and Jonides 2013), hyperactivity/impulsivity (Gibbins et al. 2012), and emotion regulation (Graziano and Garcia 2016; Gross 1998), and extends these models by suggesting that different components of these constructs may be differentially related to different underlying neurocognitive and behavioral mechanisms. For example, the working memory system includes multiple short-term 'memory' storage buffers (verbal, visual-spatial, episodic) and central executive 'working' components (updating, dual-processing, reordering; Baddeley 2007; Wager and Smith 2003). Similarly, hyperactive/impulsive symptoms have been lumped together since DSM-III (APA 1980) but at least some factor analytic studies support the conceptual distinction between hyperactivity and impulsivity (Glutting et al. 2005; Span et al. 2002), or alternatively between excess gross motor movement (hyperactivity) and auditory/verbal intrusion (Gibbins et al. 2012; Kofler et al. n.d., under review). Similarly, emotion dysregulation can result from an impaired threshold for affective arousal (i.e., emotional reactivity/lability) or from difficulties with top-down regulatory processes (i.e., emotion regulation; Graziano and Garcia 2016) that can occur secondary to disruptions at one or more stages. That is, emotion generation and expression require one to select and modify situations, actively attend to stimuli, form cognitive interpretations of events, and modulate responses accordingly (Gross 1998). Future work that identifies and fractionates working memory, hyperactivity/impulsivity, and emotion regulation into their component parts are needed to replicate and extend the current study's findings regarding independent neurocognitive and behavioral pathways to emotion regulation difficulties.

Given the current and previous findings that these emotion regulation difficulties appear to be modulated by higher-order working memory processes directly (e.g., Schmeichel et al. 2008) and potentially via an impulsive/hyperactive behavioral pathway, future work is needed to determine the point(s) in the emotion generation/expression process that this influence is conveyed. According to Gross's (1998) model, emotion regulation can occur at several different points during the process of emotion generation: the situation an individual selects, how they modify that situation to match their needs, which aspects of the environment the individual attends to, how emotional stimuli are interpreted, and how initial interpretations and reactions to stimuli are modulated by the individual. Working memory may be implicated at any of these stages of emotion generation and expression. For example, to up- or down-regulate their initial emotional responses in a socially appropriate manner, children must be able to evaluate, differentiate, and recall appropriate emotional responses for a situation, retain that information in short-term/working memory, and flexibly apply the rules corresponding to that situation. More specifically, when selecting situations, a child must be able to identify and recall situations that led to dysregulated emotions in the past, and actively maintain a representation of behaviors that were previously helpful while continually integrating incoming information from the present environment (i.e., high working memory demands). This interpretation is consistent with experimental evidence indicating that higher working memory capacity facilitates both the active suppression of emotional expressions and the ability to utilize cognitive reappraisal to modulate emotional responses (Schmeichel et al. 2008).

Limitations and Future Directions

The current study has several strengths, including a relatively large and clinically evaluated sample of children, cross-informant replication, and the multi-method, multi-informant, and multi-task design. However, the following limitations should be considered when interpreting results. First, the use of other-informant measures of emotion regulation is informative in that they measure emotion regulation using behaviors observable to parents and teachers, rather than relying on children's introspective self-report that may be hindered by limited insight, particularly in light of replicated evidence that children with ADHD reliably under-report their own symptoms and impairments (e.g., Langberg et al. 2013; Owens et al. 2007). The discrepancies between parent and teacher reported symptoms and their relations with other constructs in the current study highlight the importance of considering multi-informant ratings of children's symptoms, given that symptoms may manifest differently across settings. Additionally, these measures are limited in their ability to disentangle the mechanisms underlying emotionally dysregulated behavior, as these behaviors may be caused by deficits in emotion regulation, increased emotional reactivity or lability, or some combination of these factors. Although this study focused on the behavioral manifestation of emotion dysregulation, there is evidence that emotional reactivity and regulation may represent the same construct (Zelkowitz and Cole 2016). Both processes are impaired in children with ADHD (Graziano and Garcia 2016) and have been implicated as potential explanations of emotion dysregulation in ADHD (e.g., Christiansen et al. 2019; Graziano and Garcia 2016). Future research should investigate emotion regulation using more specific measures of emotion regulation subcomponents, including considering physiological indicators of emotional reactivity or measuring self-reported cognitive strategies involved in emotion regulation in ADHD.

Next, the current study used performance from construct-valid working memory tasks but did not examine the effects of other executive and non-executive neurocognitive functions, or subcomponents of the working memory system, in relation to ADHD symptoms and emotion dysregulation. Previous studies suggest that other executive functions, including inhibitory control and set shifting/cognitive flexibility, may be important to the etiology of emotion dysregulation (Christiansen et al. 2019; Schmeichel and Tang 2015; Wante et al. 2017). Given that patterns of deficits in executive functioning are highly variable among children with ADHD (Castellanos and Tannock 2002), it will be important for future work to consider the unique contributions of these processes in addition to working memory as they relate to emotion dysregulation. In that context, the current study's oversampling for children with ADHD was considered a strength to the extent that this heterogeneity was expected to provide a wider range of scores and thus greater likelihood of detecting interrelations among the constructs, particularly when combined with inclusion of (a) other conditions associated to greater or lesser extents with difficulties in the assessed domains, and (b) neurotypical children more likely to exhibit strengths in the assessed domains. Nonetheless, the inclusion of children without ADHD may reduce specificity of the findings to ADHD, just as the oversampling of children with ADHD may reduce generalizability to the broader population of children. Because emotion dysregulation may be a transdiagnostic factor that is associated with and/or predicts the emergence of common ADHD comorbidities (Steinberg and Drabick 2015), future work with larger samples of children with ADHD with and without comorbid diagnoses is needed to elucidate factors that contribute to emotion dysregulation in ADHD specifically. Finally, although the preponderance of evidence at this time suggests that working memory may influence emotion regulation more so than vice versa (Erk et al. 2007; Schmeichel et al. 2008; Van Dillen et al. 2009), there is some evidence to suggest these effects may be bidirectional or that emotional valence may disrupt working memory performance (Gray et al., 2002; Spies et al., 1996). The cross-sectional nature of our data prevented examination of competing models regarding directionality (Thoemmes 2015); experimental and longitudinal studies are needed to test for causality and directionality of the effects reported herein.

Clinical Implications

Taken together, the current findings were consistent with previous literature linking underdeveloped working memory with emotion regulation difficulties, while suggesting that this relation may be conveyed in part via working memory's role in controlling behavioral impulses more generally. Interestingly, hyperactivity/impulsivity showed strong covariation with emotion dysregulation, both independently and via its role as a phenotypic expression of working memory deficits that underlie the behavioral expression of ADHD symptoms. In contrast, ADHD inattentive symptoms do not appear to convey risk for difficulties with emotion regulation. These findings suggest multiple, independent pathways to emotion regulation difficulties in ADHD, with implications for understanding emotion dysregulation as a transdiagnostic risk factor for impairment (Graziano and Garcia 2016) and the development of comorbid disorders for children with ADHD (Steinberg and Drabick 2015).

Acknowledgements This work was supported in part by NIH grants (R34 MH102499-01, R01 MH115048; PI: Kofler). The sponsor had no role in design and conduct of the study; collection, management, analysis, and interpretation of the data; or preparation, review, or approval of the manuscript.

Compliance with Ethical Standards

Conflict of Interest The authors have no conflicts of interest to report.

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

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

References

Achenbach, T. M. (1991). *Manual for the child behavior checklist/4-18 and 1991 profile*. Burlington, VT: University of Vermont Department of Psychiatry.

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

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

American Psychiatric Association. (1980). *Diagnostic and statistical manual of mental disorders* (3rd ed.). Arlington, VA: APA.

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

Baddeley, A. (2007). *Working memory, thought, and action*. Oxford Press.

Banich, M. T., Mackiewicz, K. L., Depue, B. E., Whitmer, A. J., Miller, G. A., & Heller, W. (2009). Cognitive control mechanisms, emotion and memory: A neural perspective with implications for psychopathology. *Neuroscience and Biobehavioral Reviews, 33*, 613–630.

Brass, M., Ullsperger, M., Knoesche, T. R., von Cramon, D. Y., & Phillips, N. A. (2005). Who comes first? The role of the prefrontal and parietal cortex in cognitive control. *Journal of Cognitive Neuroscience, 17*, 1367–1375.

Briggs, N. E. (2006). *Estimation of the standard error and confidence interval of the indirect effect in multiple mediator models*. The Ohio State University Doctoral dissertation.

Bunford, N., Brandt, N. E., Golden, C., Dykstra, J. B., Suhr, J. A., & Owens, J. S. (2014). ADHD symptoms mediate the association between deficits in executive functioning and social impairment in children. *Journal of Abnormal Child Psychology, 43*, 133–147.

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.

Castellanos, F. X., & Tannock, R. (2002). Neuroscience of attention-deficit/hyperactivity disorder: The search for endophenotypes. *Nature Reviews Neuroscience, 3*, 617–628.

Christiansen, H., Hirsch, O., Albrecht, B., & Chavanon, M. L. (2019). Attention-deficit/hyperactivity disorder (ADHD) and emotion regulation over the life span. *Current Psychiatry Reports, 21*, 17.

Classi, P., Milton, D., Ward, S., Sarsour, K., & Johnston, J. (2012). Social and emotional difficulties in children with ADHD and the impact on school attendance and healthcare utilization. *Child and Adolescent Psychiatry and Mental Health, 6*, 33.

Conners, C. K. (2008). *Conners comprehensive behavior rating scales (Conner's CBRS)*. Toronto, Canada: Multi-Health Systems Inc..

Conway, A. R. A., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review, 12*, 769–786.

Cook, R. D., & Weisberg, S. (1982). *Residuals and influence in regression*. London: Chapman Hall.

DiStefano, C., Zhu, M., & Mîndrilă, D. (2009). Understanding and using factor scores: Considerations for the applied researcher. *Practical Assessment, Research & Evaluation, 14*, 1–11.

Dubert, C. J., Schumacher, A. M., Locker, L., Gutierrez, A. P., & Barnes, V. A. (2016). Mindfulness and emotion regulation among nursing students: Investigating the mediation effect of working memory capacity. *Mindfulness, 7*, 1061–1070.

DuPaul, G. J., Power, T. J., Anastopoulos, A. D., & Reid, R. (2016). *ADHD rating scale—5 for children and adolescents: Checklists, norms, and clinical interpretation*. New York: Guilford Press.

Erk, S., Kleczar, A., & Walter, H. (2007). Valence-specific regulation effects in a working memory task with emotional context. *Neuroimage, 37*, 623–632.

Fritz, M. S., & MacKinnon, D. P. (2007). Required sample size to detect the mediated effect. *Psychological Science, 18*, 233–239.

Gathercole, S. E., Alloway, T. P., Kirkwood, H. J., Elliott, J. G., Holmes, J., & Hilton, K. A. (2008). Attentional and executive function behaviours in children with poor working memory. *Learning and Individual Differences, 18*, 214–223.

Galanter, C. A., Carlson, G. A., Jensen, P. S., Greenhill, L. L., Davies, M., Li, W., et al. (2003). Response to methylphenidate in children with attention deficit hyperactivity disorder and manic symptoms in the multimodal treatment study of children with attention deficit hyperactivity disorder titration trial. *Journal of Child and Adolescent Psychopharmacology, 13*, 123–136.

Gibbins, C., Toplak, M. E., Flora, D. B., Weiss, M. D., & Tannock, R. (2012). Evidence for a general factor model of ADHD in adults. *Journal of Attention Disorders, 16*, 635–644.

Gioia, G. A., Isquith, P. K., Guy, S. C., & Kenworthy, L. (2000). *Behavior rating inventory of executive function: BRIEF*. Odessa, FL: Psychological Assessment Resources.

Glutting, J. J., Youngstrom, E. A., & Watkins, M. (2005). ADHD and college students: Exploratory and confirmatory factor structures with student and parent data. *Psychological Assessment, 17*, 44–55.

Gomez, R., & Sanson, A. (1994). Effects of experimenter and mother presence on the attentional performance and activity of hyperactive boys. *Journal of Abnormal Child Psychology, 22*, 517–529.

Gray, J. R., Braver, T. S., & Raichle, M. E. (2002). Integration of emotion and cognition in the lateral prefrontal cortex. *Proceedings of the National Academy of Sciences, 99*(6), 4115–4120.

Graziano, P. A., & Garcia, A. (2016). ADHD 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.

Gyurak, A., Goodkind, M., Madan, A., Kramer, J., Miller, B., & Levenson, R. (2009). Do tests of executive functioning predict ability to downregulate emotions spontaneously and when instructed to suppress? *Cognitive, Affective, & Behavioral Neuroscience, 9*, 144–152.

Gyurak, A., Goodkind, M. S., Kramer, J. H., Miller, B. L., & Levenson, R. (2012). Executive functions and the down-regulation and up-regulation of emotion. *Cognition & Emotion, 26*, 103–118.

Halperin, J. M., Trampush, J. W., Miller, C. J., Marks, D. J., & Newcorn, J. H. (2008). Neuropsychological outcome in adolescents/young adults with childhood ADHD: Profiles of persisters, remitters and controls. *Journal of Child Psychology and Psychiatry, 49*, 958–966.

Hayes, A. F. (2013). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach*. Guilford Press.

Hogarty, K. Y., Hines, C. V., Kromrey, J. D., Ferron, J. M., & Mumford, K. R. (2005). The quality factor solutions in exploratory factor analysis: The influence of sample size, communality, and overdetermination. *Educational and Psychological Measurement, 65*, 202–226.

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

Hudec, K. L., Alderson, R. M., Patros, C. H. G., Lea, S. E., Tarle, S. J., & Kasper, L. J. (2015). Hyperactivity in boys with attention-deficit/hyperactivity disorder (ADHD): The role of executive and non-executive functions. *Research in Developmental Disabilities, 45-46*, 103–109.

Karalunas, S. L., Gustafsson, H. C., Dieckmann, N. F., Tipsord, J., Mitchell, S. H., & Nigg, J. T. (2017). Heterogeneity in development of aspects of working memory predicts longitudinal attention deficit hyperactivity disorder symptom change. *Journal of Abnormal Psychology, 126*, 774.

Kasper, L. J., Alderson, R. M., & Hudec, K. L. (2012). Moderators of working memory deficits in children with ADHD: A meta-analytic review. *Clinical Psychology Review, 32*, 605–617.

Kofler, M. J., Groves, N. B., Singh, L. J., Soto, E. F., Chan, E. S. M., Irwin, L. N., & Miller, C. E. (n.d.). Rethinking hyperactivity: Preliminary evidence for a cognitively-informed re-conceptualization of hyperactivity in pediatric ADHD. *Journal of Clinical Child & Adolescent Psychology* (under review).

Kofler, M. J., Harmon, S. L., Aduen, P. A., Day, T. N., Austin, K. E., Spiegel, J. A., et al. (2018a). Neurocognitive and behavioral predictors of social problems in ADHD: A Bayesian framework. *Neuropsychology, 32*, 344.

Kofler, M. J., Irwin, L. N., Soto, E. F., Groves, N. B., Harmon, S. L., & Sarver, D. E. (2018b). Executive functioning heterogeneity in pediatric ADHD. *Journal of Abnormal Child Psychology*, 1–14.

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.

Kofler, M. J., Sarver, D. E., Harmon, S. L., Moltisanti, A., Aduen, P. A., Soto, E. F., & Ferretti, N. (2018c). Working memory and organizational skills problems in ADHD. *Journal of Child Psychology and Psychiatry, 59*, 57–67.

Kofler, M. J., Sarver, D. E., Spiegel, J. A., Day, T. N., Harmon, S. L., & Wells, E. L. (2016). Heterogeneity in ADHD: Neurocognitive predictors of peer, family, and academic functioning. *Child Neuropsychology, 23*, 733–759.

Kofler, M. J., Sarver, D. E., & Wells, E. L. (2015). Working memory and increased activity level (hyperactivity) in ADHD: Experimental evidence for a functional relation. *Journal of Attention Disorders*.

Kofler, M. J., Spiegel, J. A., Austin, K. E., Irwin, L. N., Soto, E. F., & Sarver, D. E. (2018d). Are episodic buffer processes intact in ADHD? Experimental evidence and linkage with hyperactive behavior. *Journal of Abnormal Child Psychology, 46*, 1171–1185.

Langberg, J. M., Dvorsky, M. R., & Evans, S. W. (2013). What specific facets of executive function are associated with academic functioning in youth with ADHD? *Journal of Abnormal Child Psychology, 41*, 1145–1159.

Marceau, E. M., Kelly, P. J., & Solowij, N. (2018). The relationship between executive functions and emotion regulation in females attending therapeutic community treatment for substance use disorder. *Drug and Alcohol Dependence, 182*, 58–66.

McRae, K., Gross, J. J., Weber, J., Robertson, E. R., Sokol-Hessner, P., Ray, R. D., et al. (2012). The development of emotion regulation: An fMRI study of cognitive reappraisal in children, adolescents and young adults. *Social Cognitive and Affective Neuroscience, 7*, 11–22.

Miller, E. K. (2000). The prefrontal cortex and cognitive control. *Nature Review Neuroscience, 1*, 59–65.

Nee, D. E., & Jonides, J. (2013). Neural evidence for a 3-state model of visual short-term memory. *Neuroimage, 74*, 1–11.

Opitz, P. C., Lee, I. A., Gross, J. J., & Urry, H. L. (2014). Fluid cognitive ability is a resource for successful emotion regulation in older and younger adults. *Frontiers in Psychology, 5*, 609.

Owen, A. M., McMillan, K. M., Laird, A. R., & Bullmore, E. (2005). N-back working memory paradigm: A meta-analysis of normative functional neuroimaging studies. *Human Brain Mapping, 2*, 46–59.

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.

Patros, C. H. G., Alderson, R. M., Lea, S. E., Tarle, S. J., Kasper, L. J., & Hudec, K. L. (2015). Visuospatial working memory under-lies choice-impulsivity in boys with ADHD. *Research in Developmental Disabilities, 38*, 134–144.

Polanczyk, G. V., Willcutt, E. G., Salum, G. A., Kieling, C., & Rohde, L. A. (2014). ADHD prevalence estimates across three decades: An updated systematic review and meta-regression analysis. *International Journal of Epidemiology, 43*, 434–442.

Preacher, K. J., Rucker, D. D., & Hayes, A. F. (2007). Addressing moderated mediation hypotheses: Theory, methods, and prescriptions. *Multivariate Behavioral Research, 42*, 185–227.

Qian, Y., Chang, W., He, X., Yang, L., Liu, L., Ma, Q., Li, Y., Sun, L., Qian, Q., & Wang, Y. (2016). Emotional dysregulation of ADHD in childhood predicts poor early-adulthood outcomes: A prospective follow up study. *Research in Developmental Disabilities, 59*, 428–436.

Raiker, J. S., Rapport, M. D., Kofler, M. J., & Sarver, D. E. (2012). Objectively-measured impulsivity and ADHD: Testing competing predictions from the working memory and behavioral inhibition models of ADHD. *Journal of Abnormal Child Psychology, 40*, 699–713.

Rapport, M. D., Bolden, J., Kofler, M. J., Sarver, D. E., Raiker, J. S., & Alderson, R. M. (2009). Hyperactivity in boys with ADHD: A ubiquitous core symptom or manifestation of working memory deficits? *Journal of Abnormal Child Psychology, 37*, 521–534.

Rennie, B., Beebe-Frankenberger, M., & Swanson, H. L. (2014). A longitudinal study of neuropsychological functioning and academic achievement in children with and without signs of attention-deficit/hyperactivity disorder. *Journal of Clinical and Experimental Neuropsychology, 36*, 621–635.

Reynolds, C. R., & Kamphaus, R. W. (2015). *BASC-3: Behavior assessment system for children* (3rd ed.). Upper Saddle River, NJ: Pearson Education.

Richard-Lepouriel, H., Etain, B., Hasler, R., Bellivier, F., Gard, S., Kahn, J., Prada, P., Nicastro, R., Ardu, S., Dayer, A., Leboyer, M., Aubry, J. M., Perroud, N., & Henry, C. (2016). Similarities between emotional dysregulation in adults suffering from ADHD and bipolar patients. *Journal of Affective Disorders, 198*, 230–236.

Rutherford, H. J. V., Booth, C. R., Crowley, M. J., & Mayes, L. C. (2016). Investigating the relationship between working memory and emotion regulation in mothers. *Journal of Cognitive Psychology, 28*, 52–59.

Salari, R., Bohlin, G., Rydell, A. M., & Thorell, L. B. (2017). Neuropsychological functioning and attachment representations in early school age as predictors of ADHD symptoms in late adolescence. *Child Psychiatry & Human Development, 48*, 370–384.

Sarver, D. E., Rapport, M. D., Kofler, M. J., Raiker, J., & Friedman, L. (2015). Hyperactivity in ADHD: Impairing deficit or compensatory behavior? *Journal of Abnormal Child Psychology, 43*, 1219–1232.

Schmeichel, B. J., & Tang, D. (2015). Individual differences in executive functioning and their relationship to emotional processes and responses. *Current Directions in Psychological Science, 24*, 93–98.

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.

Schweizer, S., Grahn, J., Hampshire, A., Mobbs, D., & Dalgleish, T. (2013). Training the emotional brain: Improving affective control through emotional working memory training. *The Journal of Neuroscience, 33*, 5301–5311.

Schweizer, S., Hampshire, A., & Dalgleish, T. (2011). Extending brain-training to the affective domain: Increasing cognitive and affective executive control through emotional working memory training. *PLoS One, 6*, e24372.

Schweizer, S., Samimi, Z., Hasani, J., Moradi, A., Mirdoraghi, F., & Khaleghi, M. (2017). Improving cognitive control in adolescents with post-traumatic stress disorder. *Behaviour Research and Therapy, 93*, 88.

Span, S. A., Earleywine, M., & Strybel, T. Z. (2002). Confirming the factor structure of attention deficit hyperactivity disorder symptoms in adult, nonclinical samples. *Journal of Psychopathology and Behavioral Assessment, 24*, 129–136.

Sperduti, M., Makowski, D., Arcangeli, M., Wantzen, P., Zalla, T., & Piolino, P. (2017). The distinctive role of executive functions in implicit emotion regulation. *Acta Psychologica, 173*, 13–20.

Spies, K., Hesse, F., & Hummitzsch, C. (1996). Mood and capacity in Baddeley's model of human memory. *Zeitschrift für Psychologie mit Zeitschrift für angewandte Psychologie*.

Steinberg, E., & Drabick, D. (2015). A developmental psychopathology perspective on ADHD and comorbid conditions: The role of emotion regulation. *Child Psychiatry & Human Development, 46*, 951–966.

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.

Tarle, S. J., Alderson, R. M., Arrington, E. F., & Roberts, D. K. (2019). Emotion regulation and children with attention-deficit/hyperactivity disorder: The effect of varying phonological working memory demands. *Journal of attention disorders*.

Thoemmes, F. (2015). Reversing arrows in mediation models does not distinguish plausible models. *Basic and Applied Social Psychology, 37*, 226–234.

Van Dillen, L., Heslenfeld, D., & Koole, S. (2009). Tuning down the emotional brain: An fMRI study of the effects of cognitive load on the processing of affective images. *Neuroimage, 45*, 1212–1219.

van Lieshout, M., Luman, M., Twisk, J. W., Faraone, S. V., Heslenfeld, D. J., Hartman, C. A., Hoekstra, P. J., Franke, B., Buitelaar, J. K., Rommelse, N. N., & Oosterlaan, J. (2017). Neurocognitive predictors of ADHD outcome: A 6-year follow-up study. *Journal of Abnormal Child Psychology, 45*, 261–272.

Wager, T. D., Davidson, M. L., Hughes, B. L., Lindquist, M. A., & Ochsner, K. N. (2008). Prefrontal-subcortical pathways mediating successful emotion regulation. *Neuron, 59*, 1037–1050.

Wager, T. D., & Smith, E. E. (2003). Neuroimaging studies of working memory. *Cognitive, Affective, & Behavioral Neuroscience, 3*, 255–274.

Walerius, D. M., Fogleman, N., & Rosen, P. (2016). The role of ADHD and negative emotional lability in predicting changes in parenting daily hassles. *Journal of Child and Family Studies, 25*, 2279–2291.

Wante, L., Mezulis, A., Van Beveren, M., & Braet, C. (2017). The mediating effect of adaptive and maladaptive emotion regulation strategies on executive functioning impairment and depressive symptoms among adolescents. *Child Neuropsychology, 23*, 935–919.

Waxmonsky, J., Pelham, W. E., Gnagy, E., Cummings, M. R., & O'Connor, B.…& Robb, J.A. (2008). The efficacy and tolerability of methylphenidate and behavior modification in children with ADHD and severe mood dysregulation. *Journal of Child & Adolescent Psychopharmacology, 18*, 573–588.

Wechsler, D. (2003). *Wechsler intelligence scale for children* (4th ed.). San Antonio: Pearson.

Wechsler, D. (2011). *Wechsler abbreviated scale of intelligence* (2nd ed.). San Antonio: Pearson.

Wechsler, D. (2014). *Wechsler intelligence scale for children* (5th ed.). San Antonio: Pearson.

Wells, E. L., Kofler, M. J., Soto, E. F., Schaefer, H., & Sarver, D. E. (2018). Assessing working memory in children with ADHD: Minor administration and scoring changes may improve digit span backward's construct validity. *Research in Developmental Disabilities, 72*, 166–178.

Willoughby, M., Blair, C., & Family Life Project Investigators. (2016). Measuring executive function in early childhood: A case for formative measurement. *Psychological Assessment, 28*, 319–330.

Wolfe, C. D., & Bell, M. A. (2007). The integration of cognition and emotion during infancy and early childhood: Regulatory processes associated with the development of working memory. *Brain and Cognition, 65*, 3–13.

Xiu, L., Zhou, R., & Jiang, Y. (2016). Working memory training improves emotion regulation ability: Evidence from HRV. *Physiology & Behavior, 155*, 25–29.

Zakzanis, K. K. (2001). Statistics to tell the truth, the whole truth, and nothing but the truth: Formulae, illustrative numerical examples, and heuristic interpretation of effect size analyses for neuropsychological researchers. *Archives of Clinical Neuropsychology, 16*, 653–667.

Zelkowitz, R. L., & Cole, D. A. (2016). Measures of emotion reactivity and emotion regulation: Convergent and discriminant validity. *Personality and Individual Differences, 102*, 123–132.