Routledge
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Journal of Clinical and Experimental Neuropsychology

ISSN: 1380-3395 (Print) 1744-411X (Online) Journal homepage: https://www.tandfonline.com/loi/ncen20

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To cite this article: Matilda A. Frick & Karin C. Brocki (2019) A multi-factorial perspective on ADHD and ODD in school-aged children: What is the role of cognitive regulation, temperament, and parental support?, Journal of Clinical and Experimental Neuropsychology, 41:9, 933-945, DOI: 10.1080/13803395.2019.1641185

To link to this article: https://doi.org/10.1080/13803395.2019.1641185

Published online: 08 Jul 2019.

JOURNAL OF CLINICAL AND EXPERIMENTAL NEUROPSYCHOLOGY
2019, VOL. 41, NO. 9, 933–945
https://doi.org/10.1080/13803395.2019.1641185

A multi-factorial perspective on ADHD and ODD in school-aged children: What is the role of cognitive regulation, temperament, and parental support?

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ABSTRACT

Introduction: It is well established that attention-deficit/hyperactivity disorder (ADHD) is a disorder of self-regulation. As such, ADHD is associated with disturbed cognitive regulation, extreme temperament traits, and deficient extrinsic regulation such as parenting. Despite these associations, cognitive regulation, temperament, and parenting have not previously been examined simultaneously in relation to ADHD symptoms in school-aged children. To bridge this gap of knowledge, we examined effects of these important aspects of self-regulation on symptoms of inattention, hyperactivity/impulsivity, and comorbid symptoms of oppositional defiant disorder (ODD) in children with and without a diagnosis of ADHD.

Method: The sample consisted of 77 children aged 8 to 12 years (~40% had a diagnosis of ADHD). We assessed cognitive regulation (i.e., complex inhibition and working memory) during a lab visit and parents rated child temperament (negative affect, surgency, and effortful control) and parental support. Parents and teachers rated ADHD and ODD symptoms in the child. We performed continuous analyses, informed by a dimensional perspective on ADHD.

Results: Working memory contributed independently to inattention ($\beta = -.19$, $p < .05$). Effortful control contributed independently to inattention and hyperactivity/impulsivity (βs = −.50 and −.49, ps < .01). Negative affect contributed to ODD symptoms as moderated by parental support ($\beta = .58$, $p < .01$). Specifically, for children who received lower levels of parental support there was a significant positive association between negative affect and ODD symptoms.

Conclusions: The results propose that both cognitive regulation and effortful control influence ADHD symptoms. Moreover, different factors seem to be involved in ADHD and ODD, with regulatory deficits specifically related to ADHD symptoms, and elevated negative affect specifically related to ODD symptoms. Interestingly, parenting moderated the relationship between negative affect and ODD symptoms, with a suggested protective effect of high parental support for children with high levels of negative affect.

ARTICLE HISTORY
Received 18 January 2019
Accepted 2 July 2019

KEYWORDS
ADHD; ODD; executive functions; temperament; parenting

Attention-deficit/hyperactivity disorder (ADHD) is a highly heritable (Larsson, Chang, Onofrio, & Lichtenstein, 2014), heterogeneous, neurodevelopmental disorder characterized by poor attention capabilities and elevated hyperactivity/impulsivity (American Psychiatric Association, 2013). Self-regulation concerns goal-directed behaviors and involves regulation of mental states, emotion, and behavior (Karoly, 1993). Deficient self-regulation, such as poor cognitive and temperamental regulation, lies at the very core of ADHD (Busch et al., 2002; Hinshaw, 2018; Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005). Externalizing behavior disorders such as conduct disorder (CD) and oppositional defiant disorder (ODD) are common comorbidities, present in roughly half of the cases with ADHD, possibly affecting the course, prognosis, and treatment response (Connor, Steeber, & McBurnett, 2010). CD is characterized by a repetitive and persistent pattern of violations of norms and the rights of others, whereas ODD is characterized by a recurrent pattern of anger, irritability, and oppositional behavior (American Psychiatric Association, 2013). ODD has a slightly higher prevalence than CD (Burt, Krueger, McGue, & Iacono, 2001; Nolan, Gadow, & Sprafkin, 2001) and is generally considered as a precursor of CD and of later emotional disorders (P. J. Frick & Nigg, 2012). Therefore, we examined ODD as an important comorbidity of ADHD in this study.

ADHD and ODD are distinct diagnostic categories, but empirical studies show that the symptoms are dimensional traits found also in the general population, and that these traits phenotypically and genetically represent the same phenomena as a diagnosis (Burt et al., 2001; Frick & Nigg, 2012; Martin, Hamshere, Stergiakouli, O'Donovan, & Thapar, 2014; Middeldorp et al., 2016). Etiologically, ADHD and ODD seem to have partially shared genetic liability (Coolidge, Thede, & Young, 2000), and it is

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suggested that the genetic factors interact with the environment in shaping the disorders (Beauchaine, Hinshaw, & Pang, 2010; Hinshaw, 2018; Loeber, Burke, & Pardini, 2009). However, slightly different pathways may lead to ADHD and ODD, with separate cognitive and temperamental profiles, and varying influence of environmental factors (Beauchaine et al., 2010; Martel, 2009; Nigg, 2006). Relatedly, a multiple pathway perspective on ADHD and ODD suggests that several factors influence the emergence and presence of symptoms. Cognitive, temperamental, and environmental factors such as parenting are of interest from a regulatory perspective. Specifically, cognitive regulation and aspects of temperament are intrinsic factors important for self-regulation in typical and atypical development (Nigg, 2006, 2017; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). In addition, parenting is an extrinsic regulatory factor that is hypothesized to exert direct or interactive influences on the child's self-regulatory abilities (Bernier, Carlson, & Whipple, 2010; Conway & Stifter, 2012; Deault, 2010; Frick et al., 2018).

Despite the well-grounded knowledge that cognitive regulation, aspects of temperament, and parenting all have been suggested as key factors in understanding the progression of ADHD symptoms and its comorbidity, they have never previously been assessed simultaneously in a school-aged sample. To fill this imperative gap of knowledge, we aimed to examine common and independent contributions of cognitive regulation, temperament, and parental support in a sample of 8 to 12-year-olds, of which ~40% had a diagnosis of ADHD, in relation to symptoms of inattention, hyperactivity/impulsivity, and ODD. We also wished to examine if parenting moderated the effects of cognitive regulation and aspects of temperament on inattention, hyperactivity/impulsivity, and ODD, as parenting has been suggested as a moderating factor in the shaping of symptoms (Beauchaine & McNulty, 2013; Deault, 2010; Hinshaw, 2018).

It is well recognized that ADHD is associated with deficits in cognitive regulation, or executive functioning (EF; Willcutt et al., 2005). Cognitive regulation is usually defined as a set of inter-related but separate higher order, top-down functions, that aid the individual to achieve goals by regulating thoughts and actions (Friedman & Miyake, 2017). The most established executive functions are inhibition, shifting, and working memory. Inhibition concerns the ability to override a dominant response, shifting involves the ability to flexibly shift between tasks, and working memory is the ability to monitor and update information (Garon, Bryson, & Smith, 2008). However, not everyone with ADHD display these deficits, which reflects the heterogeneity of the disorder, and calls for inclusion of several predictors in broader models (Nigg et al., 2005; Willcutt et al., 2005). In addition, dysfunction of cognitive regulation has been found to relate also to ODD, but this relation has been suggested to reflect the large overlap with ADHD (Nigg, 2006). That is, with control for ADHD the association between cognitive regulation and ODD most often disappears (e.g., Brocki, Nyberg, Thorell, & Bohlin, 2007; Oosterlaan, Scheres, & Sergeant, 2005).

During the early 2000s, several studies on the association between ADHD and temperament were published (e.g., Bussing et al., 2003; Martel & Nigg, 2006; Nigg, Goldsmith, & Sachek, 2004). Temperament is usually defined as early emerging, biologically rooted, and relatively stable, individual differences in emotionality, reactivity, and persistence/regulation (Shiner et al., 2012; Zentner & Bates, 2008). Rothbart's influential model of temperament suggests negative affect and surgency (i.e., positive affect and strong approach tendencies) as making up reactivity, and effortful control as the regulatory aspect that regulates emotion, cognition, and behavior in a top-down fashion (Rothbart, 2007). As such, effortful control and cognitive regulation both concern volitional regulation and show considerable overlap (Nigg, 2017). Therefore, it is important to include both constructs in studies to provide information on shared and separate variance of these regulatory functions (Bridgett, Oddi, Laake, Murdock, & Bachmann, 2013; Zhou, Chen, & Main, 2012). Nigg and colleagues have proposed different temperamental pathways for the separate ADHD-symptom domains. Specifically, that low effortful control contributes primarily to inattention, high surgency and low reactive control to hyperactivity/impulsivity, and negative affect to the overlap between ADHD and externalizing behavior disorders, such as ODD (Martel & Nigg, 2006; Nigg, 2006; Nigg et al., 2004). That is, negative affect may be primarily related to ODD (Loeber et al., 2009), and in line with this, ODD seems to be associated with emotional disorders to a higher degree than ADHD (Frick & Nigg, 2012).

Finally, calls have been made to add environmental factors to models examining effects of cognitive regulation and temperament on symptom levels (Nigg et al., 2004; Sjöwall, Backman, & Thorell, 2015). Indeed, parenting has been suggested to affect the presentation of ADHD and ODD symptoms (Deault, 2010; Johnston & Mash, 2001; Loeber et al., 2009). There are several possible mechanisms behind this association, one being that parents act as external regulators of the child's emotions and behaviors that in turn, and over time, shape the child's ability to self-regulate (Bernier et al., 2010; Frick et al., 2018). Another suggested mechanism would be that reciprocal effects between child characteristics and parenting exacerbate symptoms, such that a reactive temperament in the child evokes harsh parenting, that in turn

makes the child's temperament even more reactive (Johnston & Mash, 2001; Kiff, Lengua, & Zalewski, 2011; Lifford, Harold, & Thapar, 2007; Loeber et al., 2009). The latter suggests that gene-environment interactions (GxE) are at work (Rutter & Silberg, 2002; Wermter et al., 2010), in that parenting moderates the effect of the intrinsic factors. GxE refer to genetic effects on sensitivity towards environmental factors. For instance, children with a particular biological vulnerability, manifested as a highly reactive temperament or poor regulation, are proposed to be more susceptible to stressors such as poor parenting (Belsky, Bakermans-Kranenburg, & van IJzendoorn, 2007; Goforth, Pham, & Carlson, 2011). Relatedly, findings suggest that parenting may be more robustly associated with externalizing disorders such as ODD, rather than with core symptoms of ADHD (Beauchaine et al., 2010; Deault, 2010). Importantly, however, most studies only include assessment of maternal behavior, although the importance of including assessment of both parents has been stressed (Keown, 2012; Lifford et al., 2007).

In sum, the literature proposes that several self-regulatory constructs and parenting (which has an extrinsic regulatory function) influence ADHD and ODD symptoms. Consequently, it is of great importance to examine such intrinsic and extrinsic aspects of regulation simultaneously, to estimate common, independent, and interactive influences on symptom levels. A previous study showed that aspects of infant temperament and maternal sensitivity, but not cognitive regulation made independent contributions to both inattentive and hyperactive/impulsive behavior at 3 years in a typically developing sample (M. A. Frick, Forslund, & Brocki, 2018). The effects of surgency and temperamental regulation rather than of cognitive regulation on ADHD symptoms were replicated in a different typically developing sample, followed from infancy up to the age of 6 years (M. A. Frick, Bohlin, Hedqvist, & Brocki, 2018). A handful of other studies have examined independent effects of cognitive regulation and emotion regulation (a construct closely related to temperament) in relation to ADHD symptoms in school-aged children. These studies consistently showed that cognitive regulation, surgency and/or regulation thereof were independently related to ADHD symptoms (Brocki, Forslund, Frick, & Bohlin, 2017; Forslund, Brocki, Bohlin, Granqvist, & Eninger, 2016; Sjöwall et al., 2015; Sjöwall, Bohlin, Rydell, & Thorell, 2017), whereas negative affect was independently related to CD (Forslund et al., 2016). In addition, interaction effects between maternal caregiving and temperament proposes a protective effect of high quality caregiving for children with high levels of motor activity and surgency (Miller, Degnan, Hane, Fox, & Chronis-Tuscano, 2018).

In light of the above reported findings, we aimed to fill an apparent gap of knowledge on the joint contribution of intrinsic and extrinsic key aspects of regulation to ADHD and ODD. We did this by simultaneously examining effects of cognitive regulation, aspects of temperament, and parenting on symptoms of ADHD and ODD, in a group of school-aged children with a wide spectrum of ADHD symptoms present (~40% of the sample had a diagnosis of ADHD), using a dimensional approach. We set out to examine correlations, independent contributions, and whether parental support moderated contributions of cognitive regulation and temperament, as parenting has been suggested as a moderator of intrinsic factors (Deault, 2010; Kiff et al., 2011). We hypothesized that higher levels of cognitive regulation, effortful control, and parental support would be related to lower levels of inattention, hyperactivity/impulsivity, and ODD symptoms. In addition, we hypothesized that higher levels of surgency would be independently related to higher levels of hyperactivity/impulsivity (Martel, 2009; Nigg et al., 2004) and higher negative affect independently related to higher levels of ODD symptoms (Loeber et al., 2009; Nigg, 2006). Due to the large theoretical overlap between cognitive regulation and effortful control, we did not specify a directed hypothesis regarding independent contributions of these constructs to inattention and hyperactivity/impulsivity. We also did not have directed hypotheses regarding the effects of parental support, as the literature displays mixed findings.

Method

Participants

Seventy-seven children aged 8 to 12 years (m = 10.45, SD = 1.35, 59 boys, 77%) participated in the study. Thirty had a diagnosis of ADHD (mean age = 10.57 years, SD = 1.50, 23 boys, 77%) and 47 were typically developing (mean age = 10.38, SD = 1.26, 35 boys, 75%). The children with ADHD were recruited through ads in the local newspaper, on Facebook, and interest groups on the Internet (n = 16) and through child psychiatry departments (n = 14). We did not enroll children with an intellectual disability in the study. All parents of the children with ADHD reported that their child had been formally assessed and received an ADHD diagnosis. Twelve provided written certification from psychologist or psychiatrist of full ADHD assessment including neuropsychological testing (these children did not differ significantly on any of the study variables from the other children with ADHD, all $ps > .05$). Eighty percent (n = 24)

of the children with ADHD were regularly on medication. On the day of assessment, 16 of these medicated children refrained from medication, indicating that 73% (n = 22) of the individuals with ADHD were medication free during testing. Adding medication status in the regression analyses did not change the results significantly. Thus, to reduce the number of predictors in the models we did not include medication status it the final analyses. No significant differences on any of the study variables were found between medicated and unmedicated children (all *p*s > .05). Four of the children with ADHD reported a comorbid disorder of autism spectrum disorder (ASD). Excluding the individuals with an ASD diagnosis from the analyses did not change the significance levels of the results; therefore, we kept them in the study. We recruited the typically developing children via the population registration of Uppsala County, Sweden, in that information letters about the study were sent to 1000 families in the local area with children in correct age range. One hundred and sixteen interested parents responded to an on-line survey. We strived to obtain statistical similarities regarding age, sex, and socio-economic status (SES; the mean of the parents' level of education and income on a scale from 1 to 6) between the individuals with and without ADHD, by selecting typically developing children who were similar to the diagnosed children on these variables. None of the typically developing children had a psychiatric disorder. The study was performed in accordance with the national ethical standards and with the 1964 Helsinki declaration (the ethics board in Uppsala, Sweden, approved the study; EPN 2014/285). All legal guardians and children gave informed consent to participate in the study.

Procedure

The children came for a 2-hour visit at the Uppsala Child and BabyLab or at a child psychiatry department in Kista, Stockholm. A range of psychological functions were assessed (data on ADHD symptoms, working memory, and other measures not covered in this article are under review elsewhere). One or both parents together filled out the questionnaire concerning the child (62% mothers, 4% fathers, and 24% together). Mothers and fathers filled out the questionnaire regarding parenting separately. Teachers filled out questionnaires regarding ADHD and ODD symptoms. Families and teachers received gift certificates worth USD 20 and USD 10 respectively. The first author (a clinical psychologist) and four master students at their final year of the clinical psychology program at Uppsala University administered the tests. The first author scored and interpreted all data.

Measures

Cognitive regulation

Inhibition. A computerized implementation (Granvald & Marciszko, 2016) of a numerical Stroop task (van der Sluis, de Jong, & van der Leij, 2007) was used to measure inhibition. Two numbers at the time (ranging from 5 to 9) where presented to the center of a computer screen for up to 3 seconds (disappearing as soon as the child responded). The task was to answer which of the two numbers had the largest value, by pressing keys indicating "left" or "right". On congruent trials, the largest value was also larger in physical size, whereas on incongruent trials the largest value was smaller in physical size. The task consisted of 12 practice trials followed by 80 trials, half of which were congruent. Completion time was ~5 minutes. The measure for inhibition consisted of mean number of correct responses across all trials (theoretically ranging from 0–1). Reliability was .73 (split-half). This specific implementation has previously been used to predict aggression in 9-year-olds and was significantly correlated with an inhibitory anti-saccade task, indicating construct validity (Granvald & Marciszko, 2016).

Shifting

A computerized version (Granvald & Marciszko, 2016) of the Local-Global task (Huizinga, Dolan, & van der Molen, 2006) was used to assess shifting. The children were shown large (i.e., global) squares or circles made up by small (i.e., local) circles or squares, and at the bottom of the picture an additional square and circle, that were either large (indicating a global response) or small (indicating a local response; see Figure 1). In the global block (40 trials), the task was to respond to the large shape, and in the local block (40 trials), the task was to respond to the small shape, by pressing keys assigned to a square or a circle. In the last shifting block (80 trials) the task was to alternate between responding to the global and local aspect as indicated by the size of the additional square and circle at the bottom of the picture. Ten to 14 practice trials preceded the separate blocks. Completion time was ~8 minutes and reliability was .84 (split-half). The measure for shifting consisted of mean number of correct responses during the shifting trials (theoretically ranging from 0–1). This specific implementation has previously been used to predict aggression in 9-year-olds and was significantly correlated with the Trail Making Task, indicating construct validity (Granvald & Marciszko, 2016).

Working memory

Digit span from Wechsler Intelligence Scale for Children – 4th ed. (WISC-IV; Wechsler, 2004) was used to assess working memory. The experimenter

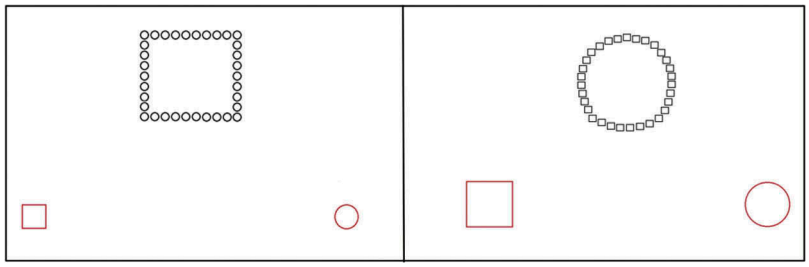

Figure 1. Image of the local-global task. The left picture signals a local response, as indicated by the small square and circle at the bottom, whereas the right picture signals a global response, as indicated by the larger figures at the bottom.

read an increasing amount of numbers to the child, who had to repeat the numbers in the correct order in the first part, and to repeat the numbers backwards in the second part. A correct response to a set of numbers rendered a score of 1. The test ended when the child gave the wrong answer to a set of numbers (e.g. three numbers) twice in a row. We used the raw score as the measure for working memory (theoretically ranging from 0–32). Digit span has excellent validity and reliability (Wechsler, 2004) and is known to be a robust test of working memory deficits in children with ADHD (e.g., Mayes & Calhoun, 2006).

Temperament

We used the revised Early Adolescence Temperament Questionnaire (EATQ-R; Ellis & Rothbart, 2001) to measure negative affect, surgency, and effortful control. Each temperamental factor consisted of three subscales; frustration, depressive mood, and aggression for negative affect (a total of 18 items, Cronbach's alpha α = .86); surgency, fear (reversed), and shyness (reversed) for surgency; and attention, inhibitory control, and activation control for effortful control (a total of 18 items, Cronbach's alpha α = .90). Fear was not significantly correlated with the other subscales for surgency and was removed from the surgency factor, yielding a factor based on 14 items with Cronbach's alpha α = .78. Parents rated temperamental characteristics in the child, such as "slams doors when angry" and "is energized by being in large crowds of people", on a scale ranging from 1 ("almost always untrue") to 5 ("almost always true"). We used the respective means of the three factors as the measures for temperament. The EATQ-R is validated in children 8 to 14 years (Muris & Meesters, 2009) and has been used to study temperament in children with ADHD, aged 6 to 14 years (De Pauw & Mervielde, 2011).

Parental support

We used the Involvement (6 items) and Conflict (8 items) scales from Parent Environment Questionnaire (PEQ; Elkins, McGue, & Iacono, 1997) to measure parental support. Both parents (76 mothers and 62 fathers) rated their relationship to the child on a scale from 0 ("definitely false") to 4 ("definitely true"). For instance, "I often criticize my son/daughter" and "my son/daughter does not want his/her friends to meet me" for conflict, and "my son/daughter talks to me about what is on his/her mind" and "I comfort my son/daughter when he/she is disappointed with something" for involvement. One item (#5, "I don't know what my sons/daughters interests are"), for mothers only, did not correlate with the other items and reduced the alpha to unacceptable levels, and was therefore dropped from further analyses. Cronbach's alpha was α = .66 (involvement for mothers), α = .74 (involvement for fathers), α = .77 (conflict for mothers), and α = .83 (conflict for fathers). The scales were correlated (r = −.43 for mothers and r = −.60 for fathers, ps < .001), and were first collapsed into a support score for each parent. Maternal and paternal support were in turn correlated (r = .42, p < .01) and collapsed into a total score for parental support. High values represent higher levels of support (that is, high involvement and low conflict). The PEQ has been validated in a large sample of 11 to 17-year-olds, with satisfactory reliability and validity (Elkins et al., 1997). The PEQ has been used to assess GxE in children aged 6 to 11 years with ADHD (Nikolas, Klump, & Burt, 2015).

ADHD symptoms

To assess inattention and hyperactivity/impulsivity we used the well-used and well-validated ADHD Rating Scale-5 for Children and Adolescents (DuPaul, Power, Anastopoulos, & Reid, 2016) based on the ADHD criteria in the Diagnostic and Statistical Manual of mental disorders, fifth edition (DSM-5; American Psychiatric Association, 2013). Parents and teachers rated nine items concerning inattention and nine items concerning hyperactivity/impulsivity on a scale from 0 ("never or rarely") to 3 ("very often"). Parent (n = 76) and teacher (n = 57) ratings were significantly correlated (*rho* = .56 for inattention and *rho* = .48 for hyperactivity/impulsivity, ps < .0001) and collapsed into one measure for each symptom domain. The

composite of parent and teacher rating was also informed by the ecological value of including ratings from two environments (i.e., home and school), as a diagnosis of ADHD according to the DSM-5 is based on symptoms present in at least two different environments (American Psychiatric Association, 2013). Cronbach's alpha for inattention was α = .95, and for hyperactivity/impulsivity α = .95.

ODD symptoms

The Swanson, Nolan, and Pelham scale-IV (SNAP-IV; Bussing et al., 2008) was used to assess the eight criteria for ODD in DSM-5 (American Psychiatric association, 2013). Parents and teachers rated each item, such as "loses temper" and "argues with adults" on a scale from 0 ("never or rarely") to 3 ("very often"). Parent (n = 76) and teacher (n = 57) ratings were correlated (*rho* = .43, $p < .001$) and were collapsed into one measure for ODD symptoms. Cronbach's alpha was α = .93. The SNAP-IV is validated in children aged 6 to 11 years (Bussing et al., 2008) and has been used extensively in assessing ODD in children with ADHD.

IQ

We used the two sub tests Block design and Information from WISC-IV (Wechsler, 2004), that had the highest loading on non-verbal and verbal IQ in the Swedish validation of WISC-IV (Wechsler, 2007), as a proxy for IQ. The scaled scores for the two tests were correlated ($r = .35$, $p = .002$) and collapsed into one measure for IQ.

Statistical analyses

We conducted the statistical analyses in SPSS statistics 25, unless stated otherwise. Data was screened for outliers (z-scores > 3), which were replaced with the nearest value that was not considered an outlier (Tabachnick & Fidell, 2001). Cook's distance was calculated to find influential cases, skewness and kurtosis were examined according to Field, and visual inspections of the standardized residuals in Q-Q-plots were conducted to examine deviations from the expected distributions (Field, 2013). All analyses were dimensional, using the full sample. We used Pearson and Spearman correlations to examine bi-variate relations. We included predictors that were significantly correlated with the criterion variables in hierarchical regression models, to examine independent contributions of the study variables. Control variables (age, sex, IQ, and SES) were included in the first step, regarding both independent contributions and interactions (see below), if significantly correlated with a predictor or criterion variable. We calculated the predicted R-squared in Minitab (Frost, 2013), to examine the risk of overfitted models due to low ratio of cases to variables. The predicted R-squared was calculated by systematic removal of each observation, followed by an estimation of how well the model could predict the removed observation. A predicted R-squared that is substantially lower than the regular R^2 indicates an overfitted model (Frost, 2013). Moderation analyses between independently contributing intrinsic factors and parental support were performed in SPSS with aid of the PROCESS tool v3.1 made by Andrew F. Hayes (www.afhayes.com). We performed the Johnson-Neyman method for the main moderation analyses, since it provides more exact estimates of the interaction effect than other methods, by computing the regression model at many different values of the moderator, not just at high, mean, and low values (Field, 2013). We performed simple slopes for visual depiction of significant relations between predictors and criterion variables at levels of parental support 1 SD below the mean, at the mean, and 1 SD above the mean.

Results

Preliminary analyses

See Table 1 for descriptive statistics. Inhibition and shifting were significantly correlated (*rho* = .49, $p < .05$) and were collapsed into one measure for complex inhibition, informed by the size of the correlation and because both tasks provide the child with a conflict that require inhibitory control to be solved. One outlier was found for ODD symptoms, two for complex inhibition, and one for working memory. Calculation of Cook's distance revealed no influential cases. Inattention, hyperactivity/impulsivity, ODD symptoms, and complex inhibition, were either skewed, kurtosed, or both, and non-parametric tests were used for analyses including these measures. The Q-Q-plots showed some deviations from the expected distribution; therefore, we used bootstrapped hierarchical regression analyses. Age was significantly correlated with complex inhibition (*rho* = .35, $p < .01$) and working memory (*rho* = .37, $p < .01$). IQ was significantly correlated with inattention (*rho* = −.29), cognitive regulation (*rho* = .29), and effortful control ($r = .33$), $ps < .05$. SES was significantly correlated with inattention (*rho* = −.26, $p < .05$), hyperactivity/impulsivity (*rho* = −.31, $p < .01$), cognitive regulation (*rho* = .25, $p < .05$), and effortful control ($r = .32$, $p < .001$). Age, IQ, and SES were therefore included as control variables in analyses concerning the respective measures. Sex was

unrelated to the study variables (*rho*s ranging from −.15 to .14, *p*s ranging from .21 to .93), and therefore left out of further analyses.

Relations between study variables

Correlations

See Table 2 for correlations between study variables. Higher levels of complex inhibition, working memory, and effortful control were related to lower levels of inattention, hyperactivity/impulsivity, and ODD symptoms. Higher levels of negative affect were related to higher levels of inattention, hyperactivity/impulsivity, and ODD symptoms. Higher levels of parental support were related to lower levels of ODD symptoms.

Hierarchical regression analyses

See Table 3 for independent contributions. Working memory and effortful control contributed independently to inattention beyond age, IQ, SES, ODD, and negative affect. In addition, effortful control contributed independently to hyperactivity/impulsivity, whereas the effect of working memory was marginally significant. Negative affect contributed independently to ODD symptoms beyond controls and the other predictors. For the regression regarding ODD symptoms there were issues with multi collinearity between inattention and hyperactivity/impulsivity. Therefore the analysis was re-run with a combined ADHD measure (the mean of inattention and hyperactivity/impulsivity), and the result remained the same. The predictors of interest explained 13–15% ($R^2\Delta$) of the variance in ADHD or ODD symptoms in each model, beyond the controls. The full models explained 63–71% of the variance in ADHD or ODD symptoms (adjusted R^2), respectively. The predicted R-squared showed a drop in 6–10% explained variance, which indicates that the models were probably not overfitted.

Moderation analyses

To reduce the number of moderation analyses, inattention and hyperactivity/impulsivity were collapsed into one measure for ADHD symptoms (i.e., the mean of inattention and hyperactivity/impulsivity). This was informed by significant inter-correlations between the symptom domains and that inattention and hyperactivity/impulsivity showed convergent results in the regression analyses regarding independent contributions. This resulted in three executed models (working memory x parental support in relation to ADHD symptoms, negative affect x parental support in relation to ODD symptoms, and effortful control x parental support in relation to ADHD symptoms). The results revealed one significant interaction effect,

Table 1. Descriptive statistics.

	n	*M* (*SD*)	Range	Skewness	Kurtosis
SES	76	4.14 (1.01)	1.5–5.5 (1–6)	−0.54	−0.42
IQ	75	9.59 (2.58)	3.5–15.5 (1–19)	−0.08	−0.22
Inattention	76	0.87 (0.67)	0–2.56 (0–3)	0.87	0.03
Hyp/Imp	76	0.69 (0.67)	0–2.39 (0–3)	0.98	−0.07
ODD	76	0.51 (0.48)	0–1.94 (0–3)	1.17	0.67
Complex inhibition	73	0.88 (0.08)	0.63–0.99 (0–1)	−1.35	1.68
Working memory	76	14.05 (2.79)	8–20 (0–32)	0.28	−0.22
Negative affect	75	2.56 (0.59)	1.51–4.39 (1–5)	0.45	0.36
Surgency	75	3.48 (0.62)	1.61–4.69 (1–5)	−0.31	0.45
Effortful control	75	3.24 (0.69)	1.86–4.56 (1–5)	−0.40	−0.76
Parental support	76	2.95 (0.41)	2.01–3.68 (0–4)	−0.49	−0.61

Note. SES = socio-economic status, Hyp/Imp = hyperactivity/impulsivity, ODD = oppositional defiant disorder

Table 2. Correlations between study variables.

	Inhibition[a]	WM	Neg aff	Surg	EC	Support	Inattention[a]	Hyp/Imp[a]	ODD[a]
Inhibition[a]	1	.29*	−.12	−.09	.24*	−.07	−.14 (−.27*)	−.18 (−.25*)	−.15 (−.23*)
WM		1	−.27*	−.08	.40***	−.03	−.48*** (−.51***)	−.53*** (−.46***)	−.35** (−.27*)
Neg aff			1	−.04	−.65***	−.47***	.46***	.43***	.68***
Surgency				1	.06	.13	−.06	−.02	.13
EC					1	.29*	−.74*** (−.73***)	−.66*** (−.69***)	−.63*** (−.60***)
Support						1	−.20+	−.10	−.35**
Inattention[a]							1	.78***	.56***
Hyp/Imp[a]								1	.60***
ODD[a]									1

Note. [a] = Spearman's *rho*, all other analyses conducted with Pearson's *r*. In parenthesis, correlations with control for age, IQ, and/or socio-economic status (SES) when these were significantly correlated with the predictor. Inhibition = complex inhibition, WM = working memory, Neg aff = negative affect, EC = effortful control, Support = parental support, Hyp/Imp = hyperactivity/impulsivity, ODD = oppositional defiant disorder; + = $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$. $n = 62–76$.

Table 3. Linear bootstrapped regression models with inattention, hyperactivity/impulsivity, or ODD symptoms as criterion variables and all variables that were significant in the correlations included as predictors in the models.

	Inattention					Hyperactivity/Impulsivity					ODD				
	B	*β*	*Adj* R^2	$R^2\Delta$	*Pred* R^2	*B*	*β*	*Adj* R^2	$R^2\Delta$	*Pred* R^2	*B*	*β*	*Adj* R^2	$R^2\Delta$	*Pred* R^2
Step 1			.52					.43					.50		
Age	0.12	0.24**				0.02	0.04				−0.05	−0.19			
IQ	−0.05	−0.19$^+$				−0.04	−0.15				0.02	0.09			
SES	−0.02	−0.03				0.01	0.02				−0.05	−0.10			
ODD	0.99	0.69**				0.96	0.66**								
ADHD											0.50	0.70**			
Step 2			.67	.15	.60			.57	.14	.48			.63	.13	.53
Inhibition	0.60	0.06				0.40	0.04				−0.70	−0.11			
WM	−0.05	−0.19*				−0.04	−0.17$^+$				0.00	0.01			
Neg aff	−0.13	−0.11				−0.06	−0.06				0.25	0.32*			
EC	−0.49	−0.50**				−0.48	−0.49**				0.06	0.09			
Support											−0.26	−0.18$^+$			

Note. SES = socio-economic status, ODD = oppositional defiant disorder, ADHD = attention-deficit/hyperactivity disorder, Inhibition = complex inhibition, WM = working memory, Neg aff = negative affect, EC = effortful control, Support = parental support, adj = adjusted, pred = predicted.
$^+$ = $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$. $n = 67$.

in that parental support moderated the relationship between negative affect and ODD symptoms, ($\beta = 0.58$, $p < .01$, $\Delta R^2 = 0.04$) indicating that for children who received low to medium levels of parental support, there was a significant positive association between negative affect and ODD symptoms (Figure 2 shows the simple slopes for the interaction). The Johnson-Neyman analysis showed that this held true when parental support was below .16 (mean centered values), which included 60% of the cases. For children who received high support there was no relationship between negative affect and ODD symptoms. The moderation analyses regarding working memory x parental support and effortful control x parental support in relation to ADHD symptoms were non-significant ($\beta = 0.10$, $p = .16$ and $\beta = -0.05$, $p = .67$).

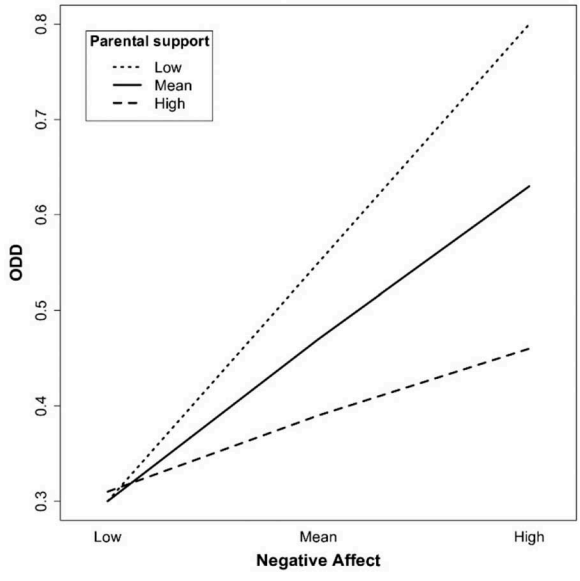

Figure 2. Simple slopes of the regression of negative affect on ODD, as moderated by parental support. Lines represent low (1 SD below the mean), mean, and high (1 SD above the mean) levels of parental support. The interaction was significant at low and mean levels of parental support ($p < .001$).

Discussion

A multi-factorial perspective on ADHD suggests that several factors influence the emergence and establishment of symptoms. Given that ADHD is best understood as a dimensional disorder characterized by poor self-regulation, we examined intrinsic and extrinsic key aspects of regulation in relation to ADHD and ODD symptoms in a school-aged sample of which ~40% had a clinical diagnosis of ADHD. We took particular care to include both intrinsic and extrinsic aspects of regulation in the same model, as there is clear lack of knowledge on how children's inner ability for self-regulation may operate in relation with family environmental factors to influence ADHD and ODD symptoms. We examined cognitive regulation, aspect of temperament, and parenting and found independent contributions of working memory and effortful control to ADHD symptoms, indicating that both cognitive and temperamental regulation are of importance in the disorder. In addition, negative affect showed an independent effect on ODD symptoms, in that more negative affect contributed to higher symptom levels. Our results imply that separate factors are at work in relation to ADHD and ODD symptoms. To be more specific, regulatory deficits were primarily associated with ADHD symptoms, whereas elevated levels of negative affect were specifically linked to symptoms of ODD. Interestingly, parenting had a moderating role on ODD symptoms, suggesting high parental support to be a protective factor for children characterized by

high negative affect. Furthermore, the common belief that high surgency is predominantly associated with hyperactivity/impulsivity may not be true for school-aged children. The results emphasize the importance of breaking down the broad construct of self-regulation into separate intrinsic and extrinsic factors, when attempting to uncover the impact of self-regulatory deficits on ADHD and ODD symptoms.

A multi-factorial perspective on ADHD

It has been suggested that effortful control would be primarily associated with inattention, whereas surgency would be primarily associated with hyperactivity/impulsivity (Martel & Nigg, 2006; Nigg, 2006; Nigg et al., 2004). Our results do not support this proposal. Specifically, we found that effortful control contributed independently to both inattention and hyperactivity/impulsivity, whereas surgency did not contribute to any of the symptom domains. In addition, working memory contributed to inattention (and marginally so to hyperactivity/impulsivity), suggesting multiple regulatory factors to be involved in ADHD symptoms generally and in inattention particularly.

We recently examined similar models in two longitudinal studies starting in infancy, including typically developing children. In those studies, we found no effect of cognitive regulation in relation to ADHD symptoms, but we did find effects of effortful control, maternal sensitivity (Frick et al., 2018), and of temperamental activity (Frick et al., 2018). A possible explanation for the differing results may be that the effect of parenting on self-regulation is stronger for typically developing children, and that the effect of cognitive regulation is stronger in clinical groups (Rajendran et al., 2013). Another plausible explanation may be that there is a developmental effect, with a stronger impact of parenting early in development due to a sensitive developmental period for environmental influences (Callaghan & Tottenham, 2016; Sulik, Blair, Mills-Koonce, Berry, & Greenberg, 2015) and an increased influence of cognitive factors on ADHD symptoms over time (Schoemaker, Mulder, Deković, & Matthys, 2013). For instance, it has previously been found that deficits in working memory were associated with ADHD symptoms in both typical and clinical samples in school-aged children but not in preschoolers, possibly explained by the protracted development of working memory with maturation well into adolescence (Brocki & Bohlin, 2006; Brocki et al., 2007). In addition, observations may be a better estimate of parenting than self-reports, which may in part explain the differing results. Similarly, the effect of cognitive regulation (i.e., working memory) on ADHD symptoms in the current study, but not in the infant studies, may be due to difficulties with assessing cognitive regulation in infants and toddlers (S. E. Miller & Marcovitch, 2015).

Contrary to our predictions and previous findings, we did not find a relationship between surgency and hyperactivity/impulsivity. We explored this lack of relationship in several ways. First, we partialled out measures of anxiety to examine if the relation was confounded by heterogeneous anxiety levels, but that was not the case. We then correlated the specific items of the surgency scale with hyperactivity/impulsivity and surprisingly found that most items were unrelated, and some even negatively correlated with hyperactivity/impulsivity. Lastly, we examined the content of the items more thoroughly, which led us to a possible conclusion that the lack of relationship between surgency and hyperactivity/impulsivity may be a result of how the temperamental trait surgency is conceptualized in the EATQ-R. Specifically, the items of the EATQ-R are tapping anticipatory expectations and exploration, such as "appreciating adventurous travelling and activities" and "looking forward to moving to a new city", and are not directly targeting positive affect and strong approach tendencies. In contrast, some previous studies with positive results (Forslund et al., 2016; Sjöwall et al., 2015) used a pure emotional measure to assess surgency, with items such as "my child often gets happy, excited and in an exuberant mood" (Rydell, Berlin, & Bohlin, 2003). Thus, the present surgency scale may tap into openness to experience, and the exploratory behaviors mentioned may be hampered by repeated social failure due to high levels of ADHD symptoms and/or few opportunities to explore the world due to socio economic reasons. Our results are in line with other studies that did not find a correlation between surgency and ADHD symptoms in school-aged children, using temperamental measures (Cukrowicz, Taylor, Schatschneider, & Iacono, 2006; De Pauw & Mervielde, 2011), possibly due to the factors just mentioned. Therefore, it may be of importance to differentiate between low-level positive affect and approach, and openness to experience when assessing surgency in older children with ADHD (De Pauw & Mervielde, 2011).

The moderate associations between working memory and effortful control, and the fact that they both contributed independently to symptoms, suggest that the two are inter-related but do not map onto the exact same construct, which is in line with recent attempts to integrate different aspects of self-regulation into larger frameworks (Bridgett et al., 2013; Nigg, 2017).

Different routes to ADHD and ODD symptoms

It has been proposed that different pathways lead to ADHD and ODD. Specifically, that poor regulation would be specific to ADHD, whereas high negative

affect and poorer quality of parenting would be associated with ODD (Beauchaine et al., 2010; Deault, 2010; Martel, 2009; Nigg et al., 2004). Our results are fully in line with these proposals. First, we found that deficient regulation was clearly and specifically related to ADHD symptoms and not to symptoms of ODD. Second, we found that negative affect was specifically related to ODD symptoms and not to symptoms of ADHD. In accordance with our predictions, we found that higher levels of cognitive regulation, effortful control, and parental support as well as lower levels of negative affect were associated with lower levels of ODD symptoms. However, negative affect was the only factor that had an independent effect on ODD symptoms beyond the other predictors (Martel, 2009). This suggests that elevated negative affect rather than poor regulation drives the display of ODD symptoms. That is, our results are in line with empirical findings of independent contributions of cognitive regulation to ADHD symptoms, and of negative affect to externalizing behavior problems (Forslund et al., 2016; Graziano, McNamara, Geffken, & Reid, 2013).

Parenting was negatively associated with ODD symptoms, but had no main effect on ODD symptoms in the regression analyses. However, a moderating effect of parental support was found, suggesting that aspects of parenting may be more strongly associated with externalizing behaviors, such as ODD symptoms, rather than with ADHD symptoms (Beauchaine et al., 2010; Deault, 2010). The results show that parental support moderated the relationship between negative affect and ODD symptoms, proposing high support to be a protective factor for children with high negative affect. The potential mechanism would be that extrinsic regulation by the parent "prevents" the emotionally dysregulated child from developing secondary oppositional symptoms, possibly due to conflict de-escalation and reinforcement of prosocial behaviors (Beauchaine et al., 2010).

The overlap between ADHD and ODD symptoms is generally large, which was also the case in the current study. However, despite this overlap, from a mechanistic and multi-factorial perspective on comorbidity it is interesting to note clearly different mechanisms involved in the two, with a moderating effect of parental support on ODD but not ADHD symptoms.

Limitations and future directions

The study has some limitations that need to be noted. Fist, the study is cross sectional and non-experimental, which means that conclusions about causality cannot be drawn. We used a dimensional approach, based on research suggesting that traits of inattention and hyperactivity/impulsivity present in the general population represent the same phenotype as in diagnostic groups (Middeldorp et al., 2016; Willcutt et al., 2012). However, the distribution of symptoms is often skewed, and the pattern of associations between for instance cognitive regulation and symptoms may come across differently in clinical and non-clinical groups (Schoemaker et al., 2013). As such, results obtained in combined clinical and non-clinical samples need to be replicated in clinical groups. In addition, a person-centered approach may yield important information on more specific pathways or trajectories for discrete groups of individuals. Further, the sample size is modest, and our ratio of boys versus girls (3.26:1) is slightly higher than what was found in a recent review (2.18:1; Thomas, Sanders, Doust, Beller, & Glasziou, 2015). Parenting is self-rated and may not fully correspond to observed or child-rated behaviors. In contrast to most previous studies, which most often contain measures of maternal behavior only, we included a measure of parenting based on *both* maternal and paternal ratings. In order to reduce the number of predictors and add power in our analyses, we used a composite measure of maternal and paternal ratings, as the number of fathers who replied was lower than the number of replying mothers. Examining the ratings separately may have contributed with additional information. In addition, rater bias may be present, as parents rated some of the predictors (i.e., temperament and parental support), and the criterion variables consist of composites of parent and teacher ratings. As ADHD diagnoses generally are based on reports of both home and school environment, we believe it is ecologically valid to include both informants in the measure. However, it is important to note that the potential rater bias, together with construct overlap, likely overestimate the explained variance in the regression models. As such, it is imperative not to solely focus on the specific magnitude of the variance accounted for in the models, but rather on the independent contributions of constructs. Future studies should use a longitudinal design and avoid rater bias by using observed measures of parenting (or cross-ratings, where the parents rate each other's parenting skills) and multiple raters, including self-ratings, of temperament and ADHD and ODD symptoms.

Conclusions

The current study is unique in bringing together intrinsic and extrinsic regulatory predictors of importance for progression of ADHD and ODD

symptoms. Specifically, we examined effects of cognitive regulation, aspects of temperament, and parenting on symptom levels in a school-aged sample oversampled for children with a diagnosis of ADHD. The study supports a multi-factorial perspective on ADHD, with contributions of key aspects of self-regulation (i.e., working memory and effortful control). Further, the study implicates that separate aspects of regulation are of importance for symptoms of ADHD and ODD respectively, with primary deficits in regulation for ADHD symptoms and elevated emotionality for ODD symptoms. Finally, high parental support had a protective effect specifically for children with high levels of high negative affect.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

The research was supported Jerringfonden, grant 2017/29, to Karin C. Brocki.

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