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Self-Regulation and Other Executive Functions Relationship to Pediatric OCD Severity and Treatment Outcome

Joseph P. H. McNamara · Adam M. Reid · Amanda M. Balkhi · Regina Bussing · Eric A. Storch · Tanya K. Murphy · Paulo A. Graziano · Andrew G. Guzick · Gary R. Geffken

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Abstract The intersection of obsessive-compulsive disorder (OCD) and executive functioning (EF) in children and adolescents is an emerging topic in the current literature. Spurred by the consistent association between increased EF deficits and higher adult obsessive-compulsive severity, a few initial studies have replicated this relationship in pediatric OCD samples and also have found preliminary evidence that EF deficits are associated with worse response to first-line psychotherapeutic or psychopharmacological treatments for pediatric OCD. This study aimed to extend the literature by providing the first comprehensive investigation of how multiple EF domains, measured repeatedly over the course of treatment, impact pediatric obsessive-compulsive severity and response to multimodal treatment. Multi-level modeling results found that deficits in shifting, inhibition, emotional control, planning/organizing, monitoring and initiating all predicted higher average obsessive compulsive severity across treatment. Interestingly, out of the eight domains of EF investigated, only emotional control moderated treatment outcome such that those with worse emotional control experienced less of a reduction in obsessive-compulsive severity during treatment. The findings generally align with previous theories for the link between EF and OCD and indicate that emotional control has important implications in the treatment of pediatric OCD. In fact, emotional control may provide one explanation for why factors such as disgust sensitivity, oppositional behavior, and third-wave behavioral treatment techniques have all been linked to pediatric OCD treatment outcome. Future research should investigate augmentation strategies that target emotional control in children and adolescents.

J. P. H. McNamara · A. M. Reid (✉) · A. M. Balkhi · R. Bussing · A. G. Guzick · G. R. Geffken
Division of Medical Psychology, Department of Psychiatry, University of Florida, P.O. Box 100234, 1600 S Archer Rd, Gainesville, FL 32611, USA
e-mail: reidam@phhp.ufl.edu

J. P. H. McNamara
e-mail: jpm2@ufl.edu

A. M. Balkhi
e-mail: Amanda.m.Balkhi@phhp.ufl.edu

R. Bussing
e-mail: rbussing@ufl.edu

A. G. Guzick
e-mail: anguzick@vassar.edu

G. R. Geffken
e-mail: geffken@ufl.edu

A. M. Reid · A. M. Balkhi · R. Bussing · G. R. Geffken
Department of Clinical and Health Psychology, University of Florida, P.O. Box 100165, 1600 S Archer Rd, Gainesville, FL 32611, USA

P. A. Graziano
Center for Children and Families & Department of Psychology, Florida International University, 11200 SW 8th Street, HLS 1 Rm. 235A, Miami, FL 33199, USA
e-mail: pgrazian@fiu.edu

E. A. Storch · T. K. Murphy
Department of Pediatrics, University of South Florida, 880 6th Street South 4th Floor, Box 7523 St., Petersburg, FL 33701, USA

E. A. Storch
e-mail: estorch@health.usf.edu

T. K. Murphy
e-mail: tmurphy@health.usf.edu

R. Bussing
Department of Pediatrics, University of Florida, PO Box 100296, Gainesville, FL 32610, USA

E. A. Storch · T. K. Murphy
Department of Psychiatry & Behavioral Neurosciences, University of South Florida, 3515 E. Fletcher Ave., Tampa, FL 33613, USA

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Introduction

Obsessive-Compulsive Disorder (OCD), a serious mental illness characterized by intrusive obsessive thoughts and compulsive behaviors, occurs in 1–2 % of children and adolescents (children and adolescents will be referred to as youth in this study) and is currently ranked among the most disabling medical disorders (Douglass et al. 1995; Murray and López 1996; Valleni-Basile et al. 1994; Zohar 1999). Due to the high prevalence in youth and the impairing nature of obsessions and/or compulsions, two common avenues of research have developed in the literature. Specifically, research has aimed to better understand the etiology and maintaining factors related to pediatric obsessive-compulsive severity and to further improve the treatment practices for pediatric OCD. Almost two decades ago, expert guidelines for the treatment of OCD suggested the use of cognitive-behavioral therapy with exposure and response prevention (CBT-ERP), selective serotonin reuptake inhibitor (SSRI) psychopharmacological treatment, and combined therapy and medication treatment (March et al. 1997). Since then, CBT-ERP with or without SSRI therapy has emerged as the first-line behavioral treatment for OCD, with 39 % (CBT-ERP) to 54 % (CBT-ERP+SSRI) of youth experiencing a reduction in their obsessive-compulsive symptoms to a subclinical level after treatment (Pediatric OCD Treatment Study 2004). However, given the fact that treatment responders often have significant residual symptoms after treatment and that a notable number of youth don't respond to treatment at all, further research into the predictors of symptom severity and treatment effectiveness is necessary.

Executive Functioning (EF) is one such factor that may help answer questions about what contributes to obsessive-compulsive symptom severity and interferes with treatment outcome. EF is a set of abilities that coordinate and control the execution of complex cognitive tasks (Miyake et al. 2000). Although described differently across disciplines in psychology, EF appears to fall under the umbrella of at least two broad, functionally defined factors: behavioral self-regulation (i.e., modulation of emotions and behaviors via inhibitory and shifting related EF processes) and cognitive self-regulation (i.e., cognitively self-managing tasks, problem solving and monitoring of performance via working memory related EF processes) (Borkowski 1996; Gioia et al. 2000; Miyake et al. 2000; Zhou et al. 2012). It should be noted that some groups argue that aspects of self-regulation stem from non-EF processes, but most agree EF pays a large role in self-regulation (Zhou et al. 2012).

The intersection of OCD and EF in youth is an emerging topic in the current literature, spurred by theoretical support and multiple studies of EF and OCD in the adult literature (Zandt et al. 2009). Theoretical arguments for how OCD relates to EF deficits in self-regulation and metacognition have been postulated (Eysenck and Calvo 1992; Olley et al. 2007) and supported by research with adult OCD samples. Adults with OCD have displayed marked difficulties in neuropsychological tasks assessing EF, such as working memory and inhibition (e.g., Bannon et al. 2006; Nakao et al. 2009; Purcell et al. 1998; Rao et al. 2008; Watkins et al. 2005). A few neurological and performance based studies have investigated and supported the relationship between EF presentation and obsessive-compulsive severity in pediatric populations, such as for difficulties with inhibition and planning or organizing (Abramovitch et al. 2012; Andrés et al. 2007; Ornstein et al. 2010), although the pediatric literature is much more sparse and discrepancies from the adult literature are notable. For example, contradictory to adult research using imaging and/or performance based assessment of working memory (e.g. Nakao et al. 2009; Purcell et al. 1998), working memory deficits in youth have been found at similar levels to peers without OCD and were not predictive of obsessive-compulsive severity (Andrés et al. 2007; Flessner et al. 2010; Ornstein et al. 2010). Similar discrepancies between the adult and pediatric literature have been observed for other EF related factors (Ornstein et al. 2010) and inconsistency certainly exists within the pediatric literature itself (Abramovitch et al. 2012). While EF is considered to be a relatively stable construct in adulthood, childhood and adolescence is a time in which EF is developing and thus consistency between the adult and pediatric literature may be an inappropriate expectation (Anderson 2002). The lack of research on EF and OCD in youth and the inconsistencies that are present between these few studies and those in adult samples supports the need for additional research on EF and OCD in youth. The literature that does exist generally focuses on how one or two aspects of executive functioning relates to obsessive-compulsive severity (e.g., Andrés et al. 2007), therefore studies that incorporate multiple aspects of EF simultaneously will provide richer data on how unique components of EF relate to obsessive-compulsive severity.

The majority of the research reviewed above has focused on cross-sectional, correlational studies investigating the association between specific EF deficits and obsessive-compulsive symptom severity. More recent research has begun to investigate how EF may relate to OCD treatment outcome. Research has shown structural changes indicative of improving EF does occur in response to multimodal psychological and psychopharmacological treatment of youth and adults with OCD (Andrés et al. 2008). More so, preliminary evidence suggests that this change is spurred more by pharmacological than psychotherapeutic agents (Lázaro et al. 2009; Rosenberg et al. 2000). This parallels research that suggests EF deficits may interfere with CBT-ERP for youth with OCD while not impacting SSRI treatment in this same population (Flament et al. 1985; Flessner et al. 2010; Ginsburg et al. 2008; Leonard et al. 1989). To begin to better understand why these differential effects are being observed, a detailed investigation illuminating how EF interferes with CBT-ERP is warranted.

Theoretically, inhibition (Chamberlain et al. 2005; e.g., due to the response prevention portion of exposure exercises), emotional control (Storch et al. 2008; e.g., due to emotional burden of obsessive-compulsive symptoms that are often triggered by exposure sessions), and planning/organizing abilities (Greisberg and McKay 2003; e.g., due to difficulty in planning and structuring self-guided exposures) could all be hypothesized to impact CBT-ERP treatment outcome. To the best of our knowledge, only one CBT-ERP outcome study has investigated how EF may impact CBT-ERP response for youth with OCD and found deficits in neuropsychological functioning were associated with worse treatment outcome (Flessner et al. 2010). Notably, this contradicts recent evidence that EF does not impact CBT-ERP outcome in the adult literature (Voderholzer et al. 2013). While some of the youth subjects were on a dual CBT-ERP and SSRI treatment regimen, decreased treatment response as a result of the neuropsychological deficits was observed primarily for the CBT-ERP only condition (Flessner et al. 2010). Since the neuropsychological measure in this study was not solely a measure of EF, these researchers concluded that EF deficits could plausibly impact CBT-ERP treatment outcome and that future research would need to identify the specific EF components underlying this interference with behavioral treatment response. Based on current statistical recommendations, addressing this gap in the literature should utilize both longitudinal data and tests of mediation/moderation within the framework of statistical growth modeling (Kahn and Schneider 2013; MacKinnon, Fairchild, and Fritz 2007; Singer and Willett 2003).

To support a longitudinal study design, measures of obsessive-compulsive severity and EF that are robust to repeated administration are essential. The Children's Yale-Brown Obsessive Compulsive Scale (CYBOCS; Scahill et al. 1997) is a clinician administered, semi-structured interview that is considered the gold-standard for the assessment of pediatric OCD symptomology. EF is more difficult to measure repeatedly than obsessive-compulsive severity, as most tests of pure functioning are sensitive to practice effects and neurological imaging during these assessments are cost prohibitive. To address these limitations, parent report measures such as the Behavior Rating Inventory of Executive Function (BRIEF) have become more commonplace in assessments of EF in clinical samples (e.g., Semrud-Clikeman et al. 2010).

The BRIEF has demonstrated clinical validity in pediatric populations with documented EF difficulties (e.g., Anderson et al. 2002; McAuley et al. 2010; McCandless and O'Laughlin 2007). The BRIEF provides a measure of EF deficits that are expressed in real world situations, which has unique clinical utility not captured by imaging or performance based measurement (Gioia et al. 2010; Olley et al. 2007). The BRIEF provides measurement of multiple aspects of EF, such as emotional control, inhibition, and monitoring, that all load onto two factors of behavioral self-regulation (titled Behavioral Regulation Index) and cognitive self-regulation (titled Metacognition Index). Thus, the BRIEF is conducive for simultaneous analysis of multiple EF related domains, although the interrelations among EF deficits measured on the BRIEF requires statistical residualization procedures to isolate each EF domain and control for multicollinearity. Similarly, the BRIEF captures EF related impairment common in several psychological conditions, such as symptoms of depression and attention-deficit/hyperactivity, thus controlling for these common OCD comorbidities is important to isolate EF impairment associated solely with obsessive-compulsive severity.

The Present Study

The current study aims to address the gaps in previous research discussed above by providing a comprehensive evaluation of how EFs link to pediatric obsessive-compulsive symptom severity and CBT-ERP treatment outcome. This study was approved by the university Internal Review Board and all study procedures, including informed consent, were conducted in adherence to this review board and the standards of the National Institute of Mental Health. Based on the literature reviewed above, it was hypothesized that both BRIEF index scores will relate to higher obsessive-compulsive symptom severity, primarily due to the inhibition and the planning/organizing subscales respectively. In terms of treatment outcome, we hypothesized three moderators of treatment outcome: inhibition, emotional control, and planning/organizing subscales. These hypotheses focus on how EF deficits would hinder the behavioral components of multimodal treatment due to evidence that response to SSRIs is not hindered by EF deficits (Flament et al. 1985; Flessner et al. 2010; Leonard et al. 1989).

Method

Participants

Participants included 56 youth (61 % male, 39 % female) with a mean age of 11.7 years (SD=3.3; range=7 to 17 years) with a primary diagnosis of OCD. Fifty-four participants were Caucasian (96 %), one was African American (2 %), and one was Asian (2 %). Altogether 11 (20 %) of participants only met DSM-IV criteria for an OCD diagnosis alone, 22 (39 %) for one comorbid condition and 23 (41 %) for two or more comorbid conditions. Comorbidities relevant to the EF analysis in this study include major depressive disorder (28.6 %) and attention-deficit hyperactivity disorder (18 %).

Procedure

Data from this study comes from a double blind randomized controlled trial where participants received weekly CBT-ERP plus one of three drug arms, sertraline at regular titration, sertraline at slow titration, or pill placebo for 18 weeks (CBT-ERP began at the 4th session). For a detailed description of study procedures please refer to Bussing and colleagues (2012). All participants had a primary diagnosis of OCD (confirmed by a diagnostic assessment using the Kiddie Schedule for Affective Disorders and Schizophrenia, Present and Lifetime Version (K-SADS-PL; Kaufman et al. 1997)) and all individuals who met criteria had at least moderate clinical severity (score of 18 or higher on the CYBOCS at screening (Scahill et al. 1997)). To enhance external validity, the study design allowed for the presence of comorbid disorders as long as OCD was the primary diagnosis, with the exception of autism, intellectual disability, bipolar disorder, and psychosis.

Measures

Diagnostic Assessment The Kiddie Schedule for Affective Disorders and Schizophrenia, Present and Lifetime Version (K-SADS-PL) is a semi-structured diagnostic interview created to identify children and adolescents who meet DSM-IV criteria for Axis I diagnoses (Kaufman et al. 1997). Interviews were conducted with both parents and participants separately. Diagnoses were made by a licensed psychologist (ES, GG) or psychiatrist (RB, TM).

Attention-Deficit and Hyperactivity Symptoms The Swanson, Nolan, and Pelham-IV-Parent Report (SNAP-IV-P, Swanson et al. 2001) is an 18-item parent-rated measure of attention-deficit and hyperactivity symptom severity, valid for ages 6–18, with good psychometric properties (Bussing et al. 2008). For this study, alpha ratings for the SNAP-IV were 0.94 for the total score. For this analysis, a dichotomized variable was created using the established clinical cut-off for a diagnosis of clinical ADHD on the SNAP-IV (Swanson et al. 2001).

Depressive Symptoms The Children's Depression Rating Scale, Revised (CDRS-R; Poznanski and Mokros 1996) is a widely used interview-based measure to assess depressive symptomology in youth ages 7–17. The scale consists of 17 clinician-rated items and has demonstrated strong psychometric properties (Mayes et al. 2010). The CDRS-R was administered baseline, at the end of weeks one through nine, 13, and at end of treatment (generally week 17). Alpha ratings at baseline were 0.80 for the CDRS-R Total Score which was used in this analysis.

Obsessive-Compulsive Symptoms The CYBOCS (Scahill et al. 1997) was administered to provide an assessment of youth's obsessive-compulsive symptom severity. The CYBOCS utilizes a five-point Likert scale and captures interference, distress, impairment, resistance and control for obsessions and compulsions which combine to create a total score of obsessive-compulsive severity. This clinician administered semi-structured interview is the gold-standard for the assessment of OCD symptomology in ages 4–18, with strong psychometric properties and test-retest reliability (Storch et al. 2004). The CYBOCS was administered at screening, baseline, at the end of weeks one through nine, 13, and 17 (or at end of study if the participant completed treatment before week 17). The total score was utilized in this study; alpha ratings at baseline were 0.82.

Executive Functioning The BRIEF (Gioia et al. 2000) was used to assess overall EF at baseline, whenever notable activation syndrome symptoms were observed on a clinician rated scale of activation syndrome (see Bussing et al. 2012), and at the completion of treatment (generally session 17). Thus all participants were administered the BRIEF at least at the beginning and end of treatment and averaged four administrations during treatment. Valid for ages 5–18, the BRIEF consists of 86 parent-report items in eight domains of EF: inhibition, set shifting, emotional control, initiation of a task, working memory, planning and organizing, and self-monitoring. Following the factor structure originally identified by Gioia and colleagues (2000), the eight subscales were combined to create a Behavioral Regulation Index (BRI; Inhibit, Shift, and Emotional Control subscales) and Metacognition Index (MI; Initiate, Working Memory, Plan/Organize, Organization of Material, and Monitor). Alpha rating at baseline was 0.96 for the BRI and 0.92 for the MI (between 0.85 and 0.96 for each BRIEF subscale). This scale is validated for general pediatric populations and has demonstrated strong psychometric properties (e.g., test-retest reliability) in clinical populations (Gioia et al. 2000). Age and gender based *T*-scores were used in all analyses involving the BRIEF.

Data Analytic Strategy

Multilevel modeling (MLM; see Singer and Willett 2003) was utilized to test the association between average EF deficits and average obsessive-compulsive symptom severity, as well as how average EF deficits moderated average treatment response. In the context of a 17-week treatment trial, MLM allows for modeling of average trends over treatment (group level analysis), as well as within subject week-to-week changes during treatment (person level analysis). Executive functions are a relatively stable construct in youth over the course of a few months (De Luca et al. 2003), although EF changes have been observed during CBT-ERP treatment (Andrés et al. 2007). Therefore, within person variability in obsessive-compulsive and EF deficits were measured. MLM has several advantages over more traditional outcome analyses (e.g., uneven timing of repeated measurement within and/or between subjects) and support for its application in randomized controlled trials is growing (Kahn and Schneider 2013).

Results

Description of Study Models

The final MLM analysis included 6 nested models: 1) an unconditional means model (UMM), 2) a linear growth model (Model A), 3) a quadratic growth model (Model B), 4) a depressive symptom covariate model (Model C), 5) an ADHD diagnosis covariate model (Model D), and 6) the EF model (Model E). The UMM model is standard to all MLM analyses and provides an indication if significant variability in obsessive-compulsive severity was observed, a requirement to proceed with the MLM analyses. Model A and B were included to model the change in the obsessive-compulsive severity over the course of treatment. Model C and D are common comorbid symptoms observed in youth with OCD that also impacts EF, therefore they were included as covariates in this analysis. Six covariate models of 1) cubic growth, 2) age, 3) gender, 4) site location, 5) drug arm (i.e., regular titration, slow titration, or placebo), and 6) linear or quadratic growth moderated by drug arm were initially included but were dropped when they did not significantly improve the overall model according to the criteria outlined below. Implications for the lack of moderation on treatment outcome by the addition of SSRI medication will be discussed in a separate paper currently in preparation by Murphy and colleagues.

Model Building Procedures

All findings for the MLM analyses followed the statistical procedures outlined by Singer and Willett (2003). All statistics for the analyses can be observed in Table 1. *Fixed Effects* refers to the group level variance and *Random Effects* refers to the person level variance in obsessive-compulsive severity. A *psuedo-R2* was calculated for the *Fixed* and *Random Effects* of each model to display the total variance explained by each predictor (Kreft and De Leeuw 1998). Throughout the modeling, the *Fixed Effects* intercept remained significant, giving the “green light” for additional modeling. To be kept for additional analyses, each model had to result in a significant reduction in the −2 Log Likelihood and a reduction in the *Akaike Information Criterion/Bayesian Information Criterion.*

The EF model first included the two BRIEF index scores of BRI and MI and their respective interactions with linear time (Model E1) and then was exactly replicated using the individual BRI (Model E2) and MI (Model E3) component subscales in place of the index score variables. For Model E3, no interactions with linear time were built based off a non-significant interaction observed in Model E1 for the MI index score. BRI subscales were entered as a separate model from the MI subscales to preserve power, allow for comparison of fit statistics, and reduce multicollinearity. Multicollinearity among and between subscales on the BRI and MI was also addressed by utilizing a residualization procedure, so that any index or subscale score entered into the model had no shared variance with other index or subscales. At convergence, all estimates were *z*-transformed to allow for direct comparison of all predictors and to gauge relative effect sizes. There were no changes in the significance pattern of the predictors modeled after adjusting for the best fitting error structure (Singer and Willett 2003).

Covariate Model Findings

In terms of the growth and covariate Models A–D, a significant negative linear (medium effect size) and positive quadratic (small effect size) growth model were observed in Model A and B, respectively. In other words, most individuals saw a notable decrease in their obsessive-compulsive severity (i.e., negative linear trend) although a few saw an increase in severity towards the end of treatment (i.e., positive quadratic). In Model C, higher depressive symptoms significantly predicted higher average obsessive-compulsive symptom severity (small effect size) while ADHD diagnostic status did not significantly relate to average obsessive-compulsive symptom severity in Model D[1]. Model D (ADHD) was retained as a covariate in all subsequent analyses because, while comorbid ADHD did not significantly explain variance in obsessive-compulsive severity, previous literature consistently supports the relationship between ADHD and EF deficits (e.g., Semrud-Clikeman et al. 2010).

[1] In previous work from our lab, we reported that an increase in average obsessive-compulsive severity predicted an increase in average depressive symptom severity during treatment (Meyer et al. 2013). In controlling for depressive symptoms in this study with the same sample as our previous study, we have found that an increase in average depressive symptoms predicted an increase in average OCD symptom severity during treatment, with a small effect size. Thus, there appears to be evidence for a bidirectional model of how depressive symptoms and obsessive-compulsive symptoms interact prospectively, however this bidirectional model would need to be tested in future research with a larger sample size and is beyond the scope of this paper.

Table 1 Multilevel modeling results for Model C-E3

	UMM	Model C	Model D	Model E1	Model E2	Model E3
Fixed effects						
Intercept	0.487(104)***	0.343(0.072)***	0.338(0.071)***	0.145(0.065)*	0.130(0.059)*	0.182(0.073)*
Depression		0.304(0.039)***	0.302(0.039)***	0.292(0.067)***	0.279(0.069)***	0.313(0.071)***
ADHD			−0.188(0.212)	−0.074(0.046)	−0.105(0.185)	−0.152(0.212)
BRI				0.221(0.093)*		
BRI X Linear				0.122(0.058)*		
MI				0.364(0.094)***		
MI X Linear				0.040(0.058)		
Inhibit					0.207(0.090)*	
Inhibit X Linear					0.044(0.072)	
Shift					0.359(0.099)***	
Shift X Linear					0.128(0.075)	
EC					0.373(0.107)**	
EC X Linear					0.207(0.080)*	
Working Memory						0.217(0.140)
Plan/Org						0.449(0.180)*
Org Material						0.089 (0.103)
Monitor						0.373(0.130)**
Initiate						0.364(0.140)*
Fit statistics						
−2LL	1,437.086	1,139.997	1,139.218	363.760	359.245	373.514
AIC	1,443.086	1,151.997	1,153.218	385.760	385.245	395.514
BIC	1,456.242	1,178.257	1,183.855	419.724	425.384	429.478
ΔFixed Psd. R^2		22.02 %	1.39 %	57.15 %	61.67 %	46.76 %
ΔRandom Psd. R^2		7.57 %	2.25 %	7.10 %	0.00 %	0.00 %

[a] Numbers presented include the calculated estimates (z-transformed) with the associated standard deviation and significance level, as well as fit statistics

[b] Table does not include Model A and B or any of the dropped covariate models to save space

[c] * $p<0.05$, ** $p<0.01$, *** $p<0.001$

[d] *UMM* Unconditional Means Model; *BRI* Behavioral Regulation Index Score; *MI* Metacognition Index; *EC* Emotional Control Subscale; *Plan/Org* Planning/Organizing; *Org Material* Organization of Material; *−2LL* −2 Log Likelihood; *AIC* Akaike Information Criterion; *BIC* Bayesian Information Criterion; *Psd* Pseudo

Results for BRI and MI Model (Model E1)

To provide a global investigation of how EF deficits relate to obsessive-compulsive symptom severity during treatment, as well as if these deficits interfere with treatment outcome, the BRI and MI index scores from the BRIEF were entered into Model E1. The interaction terms that investigate how each of these aspects of EF moderates treatment outcome were also entered simultaneously. Model E1 significantly improved upon Model D and explained 57.15 % of the remaining total between-subject variance observed in obsessive-compulsive severity during treatment. BRI displayed a strong association with average obsessive-compulsive symptom severity, as well as average treatment outcome. Specifically, a one standard deviation increase in BRI deficits predicted a 0.221 standard deviation increase in average obsessive-compulsive symptom severity ($p<0.05$). Similarly, a one standard deviation increase in the interaction term of BRI and linear slope predicted a 0.112 standard deviation increase in average obsessive-compulsive symptom severity ($p<0.05$), indicating that youth with higher BRI deficits have a shallower trajectory of average symptom reduction during treatment. Both the association between BRI and obsessive-compulsive symptom severity, as well as the impact of BRI on treatment outcome, can be considered to have small effect sizes. Metacognition Index deficits were more associated with higher average obsessive-compulsive symptom severity than BRI, but did not significantly interfere with treatment response. A one standard deviation increase in MI deficits predicted a 0.364 standard deviation increase in average obsessive-compulsive symptom severity ($p<0.000$). This association can be considered to have a medium effect size. As stated above, MI deficits did not interfere with treatment outcome.

Results for BRI Subscale Model (Model E2)

Based off the significant association BRI deficits and obsessive-compulsive severity and a significant impact on treatment outcome, all the subscales that comprise the BRI index score of the BRIEF were entered into Model E2, as well as their respective interaction terms. Model E2 significantly improved upon Model D and explained 61.67 % of the remaining between-subject variance in OCD symptom severity. Deficits in Inhibit, Shift, and Emotional Control (EC), the three subscales that compose the BRI index score, were all associated with obsessive-compulsive symptom severity with a small effect size. Specifically, a one standard deviation increase in average Inhibit, Shift or EC deficits was associated with a 0.207 ($p<0.05$), 0.359 ($p<0.001$), or 0.373 ($p<0.01$) standard deviation increase in average obsessive-compulsive symptom severity, respectively. Only EC deficits significantly impacted treatment outcome. A one standard deviation increase in the interaction term with EC and linear slope predicted a 0.207 standard deviation increase in average obsessive-compulsive symptom severity ($p<0.05$), indicating that youth with higher EC deficits have a shallower trajectory of average symptom reduction during treatment, as depicted in Fig. 1.

Results for MI Subscale Model (Model E3)

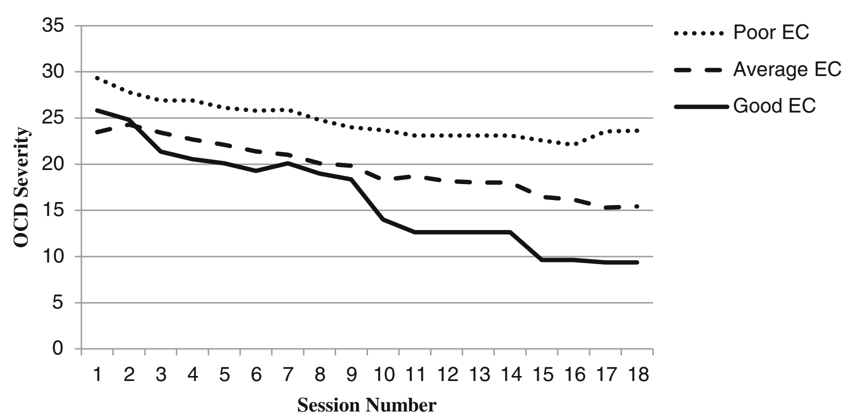
Due to the non-significant MI interaction term in Model E1, only the subscales of the MI index score were entered into Model E3. This model significantly improved upon Model D and explained 46.76 % of the remaining between subject variance in obsessive-compulsive symptom severity. Findings indicate that three out of five subscales of MC have a strong association with obsessive-compulsive symptom severity. Most notably, the Plan/Organize subscale had a large effect size in its association with obsessive-compulsive symptom severity, where a one standard deviation increase in Plan/Organize deficits predicted a 0.449 standard deviation increase in average obsessive-compulsive symptom severity ($p<0.05$). A one standard deviation increase in deficits captured by the Monitor and Initiate subscales predicted a 0.373 ($p<0.01$) and a 0.364 ($p<0.05$) standard deviation increase in average obsessive-compulsive symptom severity. Both these associations can be viewed as having a medium effect size. When controlling for all other aspects of EF, depressive symptoms and ADHD diagnostic status, working memory deficits were not found to predict average obsessive-compulsive symptom severity.

Discussion

The goal of the present longitudinal study was to examine the impact of EF on both obsessive-compulsive symptom severity and multimodal treatment response. The findings of this study are consistent with the previous literature and support the hypothesis that EF has a relationship with both symptom severity and multimodal treatment response, although in somewhat different manner than what was hypothesized. As hypothesized, both index scores predicted obsessive-compulsive severity, although this relationship appears to be driven by multiple other aspects of EF than just inhibition and planning/organizing. This is not surprising since several other EF studies have shown associations with EF in the adult literature reviewed above. One out of the three aspects of EF originally hypothesized to moderate treatment response was evident. This too echoes the adult literature where there is no evidence that EF may impact treatment outcome for CBT-ERP (Voderholzer et al. 2013), although this study did not investigate emotional regulation. This study advances the literature on this topic by using a multimodal treatment paradigm, investigating multiple EF related domains simultaneously, and utilizing multiple measurements in combination with advance statistics to capture the prospective relationship between EF and pediatric OCD.

Findings indicated that greater impairment in multiple domains of EF were associated with increased obsessive-compulsive symptom severity. As discussed in the

Fig. 1 Emotional control moderation of CBT-ERP outcome. [a]Session 1 represents the baseline assessment, which is then followed by the 17 treatment sessions. [b]Average EC scores were split into Good (N = 11), Average (N = 34), and Poor EC (N = 11) based off normal distribution theory



"Introduction", the BRIEF is a measure of EF presentation versus neurological localization and thus provides preliminary evidence for how EF deficits associated with obsessive-compulsive severity are likely to present in day-to-day situations. Taken together, youth who have more problems with controlling impulses or stopping behavior, switching from one task/situation to another or flexibility in problem solving, appropriate modulation of emotional responses, anticipating future events or creating steps to accomplish a future goal, and self-monitoring of own performance are more likely to have higher obsessive-compulsive symptom severity.

Several theories for the link between EF and OCD have been postulated. Eysenck and Calvo have proposed a broad model where anxiety increases burden on the EF systems and thus lowers efficiency (Processing Efficiency Theory; Eysenck and Calvo 1992). More recently, Olley and colleagues (2007) conducted an extensive literature review and concluded that OCD burdens the EF system by slowing response time, requiring increased perseveration on previous incorrect feedback, increasing behaviors and cognitions related to checking performance, worsening adaption to environmental feedback, and increasing inability to spontaneously generate alternative solutions and organizational strategies. These theories, based on research using traditional imaging and performance based EF measures, align closely with the domains on the BRIEF shown to relate to increased obsessive-compulsive severity in this study.

While several aspects of EF predicted obsessive-compulsive severity, only EC deficits moderated treatment outcome such that those with lower ability to modulate emotional responses had less response to CBT-ERP treatment. EC is a concept that connects various otherwise unrelated factors shown to relate to obsessive-compulsive severity and/or outcome. For example, EC has been hypothesized to underlie high disgust propensity (Olatunji et al. 2011) and disruptive behavioral disorders (Blandon et al. 2010), both of which lower response rate to CBT-ERP (Olatunji et al. 2011; Storch et al. 2008). Finally, some have suggested that improved emotional regulation is a key to the success of third-wave behavioral treatments in improving obsessive-compulsive symptom severity (Hayes and Feldman 2004).

In a seminal paper by Foa and Kozak (1986), it was proposed that in order for an exposure session to be effective, the patient must become moderately anxious to appropriately activate and modify their fear structure. Moderate anxiety induction requires that an individual must be able to appropriately regulate and cope with this emotional stress to engage in CBT-ERP. This is one hypothesis as to why those with more difficulty modulating emotional responses showed a worse response to CBT-ERP in this study and why previous research has found that baseline levels of emotional and behavioral dysregulation predict drop-out in CBT-ERP for pediatric OCD (McGuire et al. 2013). Based off these results and previous research, augmentation strategies that improve emotional regulation may be warranted. Components used in validated treatments such as trauma-focused cognitive behavioral therapy (TFCBT) and acceptance and commitment therapy (ACT) that are known to improve emotional regulation may be appropriate to integrate into CBT-ERP, such as teaching the child and parent to communicate and appropriately interpret emotional experiences or teaching mindfulness based techniques (Cohen et al. 2010; Fairfax 2008). For example, utilizing an emotion labeling exercise during initial CBT-ERP psychoeducation and prior to the initiation of any ERP exercises might help improve effectiveness.

The present study has numerous strengths, primarily that the analyses utilized advanced statistical techniques, controlled for several relevant covariates, and simultaneously studied multiple domains of EF. Despite its strengths, this study is not without limitations. While large enough for MLM, larger sample sizes would allow for use of statistical techniques such as autoregressive cross-lagged growth modeling that can answer more advanced questions such as the "chicken or the egg" causality dilemma between EF and OCD. Another weakness is the use of the BRIEF, as it has some phenomenological overlap with normal OCD symptom presentation (e.g., questions about the child's general difficulty in stopping behavior on the BRIEF and the repetitive, time-consuming nature of obsessive-compulsive behaviors). While this phenomenological overlap is a limitation, parents are instructed on the BRIEF to answer the questions about their youth's behavior or emotions in general over the past 6 months in a variety of *non-OCD* specific situations at home or at school and the BRIEF subscales or index scores had a wide range in the strength of correlations with obsessive-compulsive severity more than (0.044–0.449). For example, on EC related questions, parents are asked about how often their youth "has explosive, angry outbursts" or "becomes upset too easily." We observed a 0.373 association between EC and obsessive-compulsive symptom severity, highlighting that there is approximately 86 % of the variance in EC deficits that is unique from obsessive-compulsive symptom severity. This parallels the literature suggesting that EF deficits are a clear trait of OCD (e.g., Chamberlain et al. 2005; Nielen and Den Boer 2003). Regardless, using an impairment measure such as the BRIEF means the results observed in this study may stem from shared underpinnings in EF and OCD symptom presentation (e.g., intrusive thoughts may cause difficulties in paying attention).

Future longitudinal research simultaneously using both EF localization and impairment measures, spanning a time during the first development of symptoms, could address these limitations. In this vein, more detailed assessment of emotional control may lend more insight into how emotional regulation interferes with treatment outcome; the assessment of emotional regulation in youth is a growing field (Adrian et al. 2011;

MacDermott et al. 2010). In conclusion, the present study's findings indicate that EF has a relationship with both symptom severity and treatment response. Specifically, several domains of EF predicted increased obsessive-compulsive severity and EC deficits impacted multimodal treatment outcome. Implementing aspects of TFCBT or ACT with CBT-ERP might lead to improved treatment outcomes for youth with deficits in emotional control.

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Conflict of Interest Dr. Regina Bussing has received research support from Pfizer Inc. and Otsuka Pharmaceuticals. She also has served as a consultant for Pfizer Inc. and Shire Pharmaceuticals and has received travel support and honorarium to present original research findings at meetings in Germany. Dr. Tanya Murphy reports research support from the AstraZeneca Neuroscience iMED, Otsuka Pharmaceuticals, Shire Pharmaceuticals, National Institute of Health/National Institute of Mental Health, Center for Disease Control, International Obsessive-Compulsive Disorder Foundation, Ortho-McNeil Janssen Pharmaceuticals, Pfizer Inc., and Massachusetts General Hospital. She also reports travel support from the Tourette Syndrome Association. Finally, Dr. Eric Storch reports research support from the National Institute of Health, Center for Disease Control, Agency for Healthcare Research and Quality, International Obsessive-Compulsive Disorder Foundation, and Ortho-McNeil Janssen Pharmaceuticals. All other authors of this paper have no conflicts of interest to report.

Experiment Participants This study was approved by the university Internal Review Board and all study procedures, including informed consent, were conducted in adherence to this review board and the standards of the National Institute of Mental Health.

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