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ORIGINAL ARTICLE

The effects of childhood inattention and anxiety on executive functioning: inhibition, updating, and shifting

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Abstract

Although anxiety and attention-deficit/hyperactivity disorder (ADHD) symptoms are highly comorbid, research has generally examined the executive functioning (EF) deficits associated with each of these symptoms independently. The purpose of this study was to examine the unique and interactive effects of anxiety and ADHD symptoms (first respectively, then collectively) on multiple dimensions of EF (i.e., inhibition, updating, and shifting, respectively). A sample of 142 youth from the community (age range 8–17 years; $M_{age} = 11.87 \pm 2.94$ years) completed the Delis–Kaplan Executive Function System and dimensional measures of anxiety, inattention, and hyperactivity/impulsivity. It was hypothesized that anxiety would moderate the effect of ADHD symptomatology on EF. Multiple regression models examined anxiety and ADHD symptom domains as predictors of EF. When examining ADHD symptom domains separately, anxiety moderated the relationship between inattention and both updating and shifting; the association between hyperactivity/impulsivity and updating was also moderated by anxiety. Within the full model including both ADHD symptom domains, results indicated that anxiety moderated the relationship between inattention and shifting. Analyses of ADHD symptoms in separate and combined models demonstrated a similar pattern: Increased inattention was associated with worse EF and when anxiety was a significant moderator, and increased ADHD symptoms were associated with worse EF only for those with high levels of anxiety. These results highlight the utility of including anxiety in studies examining the relationship between ADHD and EF. EF is related to multiple aspects of daily functioning (e.g., academic achievement), and EF deficits are often targeted in interventions for ADHD.

Keywords Inattention · Hyperactivity · Executive functioning · ADHD · Anxiety

Introduction

Childhood ADHD and anxiety often co-occur (see Jarrett and Ollendick 2008; Schatz and Rostain 2006 for reviews), with comorbidity rates ranging from 11 to 40% in youth (Larson et al. 2011). Theories of ADHD have focused on its relationship to deficits in executive functioning (EF; Barkley 1997). EF refers to a number of mental functions that work as a system to control the management of activities and integrate new stimulus moment-to-moment (Brown 2006). These mental functions allow for the management of various daily tasks. As the demands of these daily tasks increase over development, children must adapt to increase their overall self-management. Comorbid anxiety has been found to improve or worsen EF in different studies, which may reflect vastly different approaches and methodology among the research in this area (e.g., Emerson et al. 2005; Muris et al. 1999, 2001, 2003, 2011; Visu-Petra et al. 2010, 2014; Toren et al. 2000).

EF varies widely in how it is defined and measured in the literature. One model of cognitive aspects of EF that has empirical support is the three-factor model of EF that includes inhibition, updating, and shifting (Miyake et al. 2000). Inhibition is the ability to delay reward by dismissing a prepotent or dominant response. For example, a child may have an impulse to answer a question aloud during class but instead shows restraint by raising his or her hand to answer the question. Updating is the ability to alter and monitor working memory representations in light of novel information. For instance, a child may incorporate new information into a list of tasks he or she was told to complete. Shifting

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reflects one's ability to think flexibly or alter mental sets or tasks. Behaviorally, a child may be unaffected by sudden changes in routine, reflecting greater cognitive flexibility. Although correlated, these factors are distinct (Friedman and Miyake 2016).

Given the high co-occurrence anxiety, inattention, and hyperactivity/impulsivity symptoms have during childhood, research would benefit from a better understanding of the unique and interactive effects these dimensional symptoms have on EF performance. This research is of particular importance given the vast functional and/or emotional difficulties associated with even slight deficits in EF (Holmes and Pizzagalli 2007). For instance, individual differences in EF deficits are associated with interpersonal difficulties (De Panfilis et al. 2013; Sprague et al. 2011), poorer physical health (Falkowski et al. 2013; Hall et al. 2006), lower academic and occupational functioning (e.g., Best et al. 2009; Miller et al. 2012; Valiente et al. 2013), increased substance use (Nigg et al. 2006), and more mental health difficulties (e.g., Willcutt et al. 2005). Moreover, EF is relatively stable over time, and although EF dimensions are correlated with one another, they can vary in their association with other clinically relevant individual differences (Friedman et al. 2007, 2011; Young et al. 2009). A recent review of the treatment literature found high levels of comorbidity between ADHD and an anxiety disorder, where youth with a comorbid diagnosis of ADHD and/or with elevated ADHD symptoms had worse treatment (e.g., CBT) outcomes than their counterparts (Halldorsdottir and Ollendick 2014).

ADHD and executive functioning

Wodka and colleagues (2008) found that youth with ADHD-combined presentation had significant deficits on EF performance, as measured by the Delis–Kaplan Function System (D–KEFS). These findings are particularly noteworthy as the various subtests of the D–KEFS have been shown to primarily measure separate EF domains (i.e., inhibition, updating, and shifting; Latzman and Markon 2010). Similarly, a meta-analysis (Willcutt et al. 2005) found group differences on EF measures between those with and without ADHD-combined type ($d = .4$–$.6$), the magnitude was much smaller than the group difference in ADHD symptoms ($d = 2.5$–4.0).

The relationship between hyperactivity/impulsivity symptomatology and EF has seldom been examined independently from inattention. Instead, the literature to date has focused on examining group differences between two ADHD subtypes (i.e., ADHD-combined presentation [ADHD-C] and ADHD-predominantly inattentive [ADHD-I]). Research has consistently found that the two groups have poorer performance on EF measures compared to matched controls (Barkley et al. 1992; Fischer et al. 2005; Geurts et al. 2005; Houghton et al. 1999; Martel et al. 2007; Nigg et al. 2002). While research is less consistent, there is some evidence that children with ADHD-C may have more EF deficits compared to those with ADHD-I (Barkley 1997; Barkley et al. 1992; Chhabildas et al. 2001; Martel et al. 2007; Nigg 2001; Nigg et al. 2005; Houghton et al. 1999), which may last into adulthood (Fischer et al. 2005); however, this result has not always been found (Geurts et al. 2005).

Unfortunately, only a few, small studies have examined the third ADHD subtype, ADHD-predominantly hyperactive/impulsive, possibly due to its low base rate. While interpreted with caution, four studies included the DSM-IV hyperactive-impulsive type in their analyses (Bedard et al. 2003; Chhabildas et al. 2001; Pitcher et al. 2002; Schmitz et al. 2002). Interestingly, these preliminary results suggest that the hyperactive-impulsive type may be associated with less EF impairment ($d = .14$; Pitcher et al. 2002).

Anxiety and executive functioning

Self-reported behavioral inhibition has been found to be positively associated with symptoms of anxiety and depression in children and adolescents (Muris et al. 2001, 1999). Muris et al. (2003) replicated and extended these findings to parent-reported behavioral inhibition. However, longitudinal structural equation modeling has indicated that behavioral inhibition acts as a specific risk factor for the development of social anxiety symptoms (Muris et al. 2011). The research by Muris and colleagues suggest that youth with anxiety may have better inhibition, but when it is combined with a myriad of other risk factors, it is associated with social anxiety symptoms later in development. Similar to self-reported inhibition, clinical anxiety has been found to be associated with excessive response inhibition on EF performance measures; however, this leads to decreased task accuracy (i.e., increased omissions).

Overall, these researchers suggest that clinical anxiety is associated with overactivation of an adaptive defense mechanism, which promotes an excessive response inhibition tendency, leading to a maladaptive behavioral effect (i.e., impaired go performance). In contrast, there is preliminary evidence that clinical and nonclinical samples of anxious children and adolescents perform worse on measures of shifting and updating (Emerson et al. 2005; Toren et al. 2000; Visu-Petra et al. 2014). For example, worse performance on spatial working memory (Visu-Petra et al. 2014) and updating working memory tasks (Visu-Petra et al. 2010) have been linked to elevated levels of trait anxiety in children. The focus of these studies was on anxiety; therefore, the effect highly comorbid inattentive and hyperactive/impulsive symptoms may have on this relationship is largely unknown.

ADHD, anxiety, and executive functioning

Research on EF performance in those with ADHD and comorbid anxiety has yielded mixed findings which may reflect differences in the domain of EF examined. The literature has demonstrated that children with ADHD and comorbid anxiety have increased working memory deficits (Jarrett et al. 2012; Pliszka 1989; Skirbekk et al. 2011; Tannock 2009; Tannock et al. 1995). Although a meta-analysis of the clinical literature did not find evidence for this association (Oosterlaan and Sergeant 1998), most researchers have found that ADHD and comorbid anxiety improves response inhibition (Manassis et al. 2000; Pliszka 1992; Pliszka et al. 1993). Some have even demonstrated that and the presence of anxiety may have mitigating effect on ADHD-related EF impairments (Yurtbaşı et al. 2018). Children with ADHD and comorbid anxiety have also been found to have enhanced sustained attention and selective attention during some laboratory tasks (compared to noncomorbid ADHD controls; Ruf et al. 2016; Vloet et al. 2010).

Overall, a review of the literature suggested that comorbid anxiety may ameliorate ADHD EF performance deficits on response inhibition, but it may impair updating (Jarrett et al. 2012; Schatz and Rostain 2006) and shifting performance (Visu-Petra et al. 2010, 2014). These cognitive differences and inconclusive literature have led some to speculate, more broadly, that children with ADHD and anxiety tend to perform worse on more cognitively complex and mentally effortful tasks; Jarrett and colleagues (2012) suggest the possibility that moderate anxiety may enhance vigilance, regulate impulses, but disrupt cognitively effortful processes such as working memory (Tannock 2009). These studies have focused on categorical diagnoses of ADHD rather than examining symptom dimensions of ADHD which may vary in their association with EF.

Current study

ADHD and anxiety are commonly comorbid (Jarrett and Ollendick 2008 and Schatz and Rostain 2006 for reviews) and the literature suggests that ADHD and anxiety have a differential relationship with EF. Previous literature has been hindered by focusing on EF differences among diagnostic groups; we look to extend the literature by examining symptom dimensions (i.e., inattention, hyperactivity/impulsivity, and anxiety) together in the same model. Unfortunately, there is a paucity of research examining the independent relationships between inattention, hyperactivity, anxiety, and EF, with no studies exploring the three-factor model of EF (Miyake et al. 2000). While anxious children may be more behaviorally inhibited (via self-, parent report, and EF performance measures) Therefore, we hypothesized that inattention and EF performance will have a negative relationship when youth have high (but not low) levels of anxiety on shifting, working memory, but not inhibition. In parallel, it is posited that there will be a similar, but less robust (Bedard et al. 2003; Chhabildas et al. 2001; Schmitz et al. 2002) relationship when examining this same association with hyperactivity/impulsivity and EF performance independently.

Method

Participants

The present study included a total of 142 nonclinical youth (age range, 8–17 years; $M_{age} = 11.87 \pm 2.94$ years; 78 males and 64 females; see Table 1). The majority of the sample identified as White ($n = 89$; 62.7%), with the remaining participants identifying as Black or African–American ($n = 34$; 23.9%), Asian ($n = 8$; 5.6%), other ($n = 6$; 4.2%), and American Indian or Native Alaskan ($n = 5$; 3.5%). The participants were obtained from the NKI/Rockland Sample (NKI-RS) provided by the Nathan Kline Institute (NKI, NY, USA),

Table 1 Demographic information of child participants

	Total sample $N = 142$
Age in years	
Mean (SD)	11.87 (2.94)
Range	8–17
Gender	
Male	78 (54.9%)
Female	64 (45.1%)
Race	
White	89 (62.7%)
Black or African–American	34 (23.9%)
Asian	8 (5.6%)
Other	6 (4.2%)
American Indian or Native Alaskan	5 (3.5%)
Psychopathology measures *M* (SD)	
Inattention symptomatology	54.70 (13.74)
Hyperactivity/impulsivity symptomatology	52.58 (12.42)
Anxious symptomatology	49.40 (10.21)
D–KEFS composites	
Inhibition	9.74 (2.47)
Updating	10.27 (2.08)
Shifting	10.22 (2.43)

which is a publicly available online database at the International Neuroimaging Data-sharing Initiative (INDI) (http://fcon_1000.projects.nitrc.org/indi/pro/nki.html; Nooner et al. 2012). The NKI institutional review board reviewed all approvals and procedures for collection and sharing of data. Written informed consent and child assent were obtained from each participant. For children who were unable to give informed consent, written informed consent was obtained from their legal guardian.

Measures

Child behavior checklist (CBCL)

The CBCL (Achenbach and Rescorla 2001) is a parent-reported screening measure for emotional and behavioral problems in children between the ages of 6 and 16 years of age. It contains 113-items rated from 0 to 2. There is strong evidence for the reliability, convergent validity and discriminative validity of the CBCL (Nakamura et al. 2009). Eight empirically syndrome scales are derived (i.e., Anxious/Depressed, Withdrawn/Depressed, Somatic Complaints, Social Problems, Thought Problems, Attention Problems, Rule-Breaking Behavior, and Aggressive Behavior). The current study utilized the Attention Problems subscale ($\alpha = .84$), which has demonstrated construct validity through its ability to significantly predict those with and without an ADHD diagnosis (Ostrander et al. 1998).

Conners' parent rating scales—revised: short form (CPRS-R-S)

The CPRS-R-S (Conners 1997) is a parent report of their child's ADHD symptomatology. The CPRS-R-S has 27-items and consists of four subscales: oppositional, cognitive problems, hyperactivity/impulsivity, as well as an ADHD Index. Psychometric properties of the CPRS-R-S have been found to be adequate, where the scale has been found to have good internal reliability coefficients, high test–retest reliability and effective discriminative power (Conners et al. 1998). The current study utilized the hyperactivity/impulsivity subscale ($\alpha = .87$).

Multidimensional anxiety scale for children (MASC)

The MASC (March 1998) is a child self-report questionnaire for symptoms of anxiety consisting of 45-items. The four empirically derived factor scores are Social Anxiety, Separation Anxiety, Harm Avoidance, and Physical Symptoms, which comprise the MASC total score. The MASC has demonstrated good internal consistency (.70–.83) and Cronbach's alpha ranging from .74 to .85 (March 1998). Further, the MASC has demonstrated good convergent validity (Baldwin and Dadds 2007), good concurrent validity (Rynn et al. 2006), adequate divergent validity, and good test–retest reliability (March et al. 1997). The current study used the total score as a measure of anxious symptomatology ($\alpha = .94$).

Delis–Kaplan executive functioning system (D–KEFS)

The current study created composites based on Latzman and Markon's (2010) factor structure of a large sample of youth aged 8–19. Specifically, the Color-Word Interference Test (i.e., Inhibition and Inhibition/Switching) and The Trail Making Test (i.e., Trails A/B) were used as a measure of inhibition, the Verbal Fluency Test (i.e., Letter Fluency, Category Fluency, Category Switching Total, and Category Switching Accuracy) as a measure of updating, and the Sorting Test (i.e., Free Sort, Free Sort Description, and Sort Recognition) as a measure of shifting.

Data analysis

Bivariate correlations were conducted to examine the relationship among composites of executive functioning (see Table 2). Multiple regression was used to examine the relationship of inattention, hyperactivity/impulsivity, and anxiety with

Table 2 Pearson correlations, means, and standard deviations of measured variables

Variable	1.	2.	3.	4.	5.	6.	*M*	SD	*n*
1. Inattention	1.0						54.70	13.74	142
2. Hyperactivity/impulsivity	.58**	1.0					52.58	12.42	141
3. Anxiety	.01	−.01	1.0				49.40	10.21	142
4. Inhibition	−.24**	−.17*	.07	1.0			9.74	2.47	132
5. Updating	−.18*	−.09	.05	.49**	1.0		10.27	2.08	142
6. Shifting	−.24**	−.19*	−.04	.43**	.35**	1.0	10.22	2.43	113

*$p < .05$, **$p < .001$; inattention = inattention subscale *t* score of the Child Behavior Checklist; hyperactivity/impulsivity = hyperactivity/impulsivity subscale *t* score of Conners' Parent Rating Scales—Revised: Short Form; anxiety = total anxiety *t* score from multidimensional anxiety scale for children; inhibition, updating, and shifting = composites from select subtests of the Delis–Kaplan executive functioning system

executive functioning. Six independent multiple regression models were conducted with each model predicting one of the various EF domains (i.e., inhibition, shifting, and updating). Specifically, three independent models utilized inattention and anxiety (step 1), as well as their interaction (step 2), when predicting inhibition, shifting, and updating (independently); three models utilized hyperactivity/impulsivity and anxiety (step 1), their interaction (step 2), again, predicting inhibition, shifting, and updating (independently).

Finally, three multiple regression models were used to examine inattention and hyperactivity/impulsivity jointly, anxiety, and then their respective interactions with anxiety. The first step of the three multiple regression analyses, conducted in parallel, included the three main effects (i.e., inattention, anxiety, and hyperactivity/impulsivity), and the second step included both two-way interactions (i.e., inattention by anxiety and hyperactivity/impulsivity by anxiety) when predicting inhibition, shifting, and updating, independently.

All regressions were analyzed in the same manner. The first step (or model) was examined if it predicted EF performance better than the intercept only model, and the second step (or model), in which one or more interactions between anxiety and ADHD symptoms were added, was only examined if it significantly improved model fit above and beyond the main effects in step one. Following a significant moderation in step two, simple slopes analyses were conducted to further explore the nature of the interaction. Age was not used as a covariate because all variables included in the models have already been controlled for age differences (centered *t* scores). In addition, gender was not used as a covariate because EF performance (i.e., inhibition, updating, and shifting) did not differ between girls and boys, as determined by Spearman's Rho values ($p > .05$).

Results

Bivariate correlations

The inhibition, shifting, and updating composites were only moderately correlated with one another, which provided justification for examining potentially differential relationships with inattention and anxiety (see Table 2). While anxiety was not correlated with any other study variables, regression analyses continued to use anxiety as an independent variable due to our hypothesis that there would be an interactive effect.

Independent models: inattention, anxiety, and their interaction: predicting executive functioning domains

Inhibition

Inattention, anxiety, and their interaction were examined as predictors of the executive functioning domains inhibition, shifting, and updating (respectively). With inhibition performance as the criterion variable, the overall model was significant, $F\ (2, 129) = 4.50$, $p < .05$, Adjusted $R^2 = .05$, where greater inattentive ($\beta = -.25$, $t(129) = -2.88$, $p < .01$), but not anxiety, symptoms were predictive of worse performance. The addition of the interaction of inattention and anxiety in the second step was not significant ($p > .05$).

Shifting

Next, inattention, anxiety, and their interaction were explored as predictors of shifting performance. The overall model was significant, $F\ (3, 109) = 4.65$, $p < .01$, Adjusted $R^2 = .09$, where greater inattentive ($\beta = -.29$, $t(109) = -3.18$, $p < .01$)., but not anxiety, symptoms were predictive of worse shifting performance. Additionally, the interaction of inattention and anxiety ($\beta = -.23$, $t(109) = -2.51$, $p < .05$) improved prediction of poor shifting performance beyond inattention and anxiety alone, $\Delta R^2 = .05$, $p < .05$. Simple slopes analyses revealed that for individuals with high anxiety scores (i.e., one standard deviation above the mean), inattention was negatively associated with shifting ($\beta = -.54$, $t(109) = -3.64$, $p < .01$). This relationship was not significant for individuals low in anxiety (i.e., one standard deviation below the mean) ($\beta = -.05$, $t(109) = -.38$, $p > .05$). See Fig. 1.

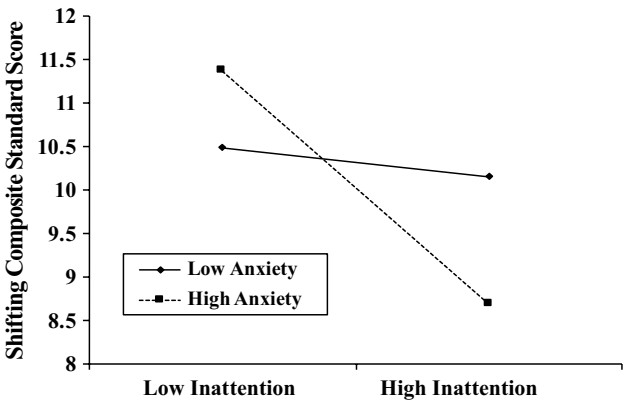

Fig. 1 Interaction between anxiety, inattention, and shifting composite

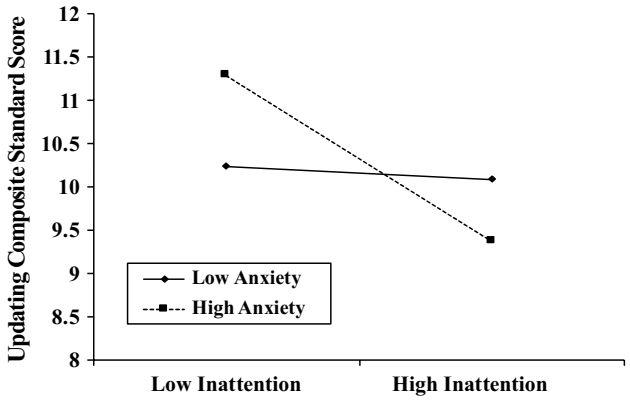

Fig. 2 Interaction between anxiety, inattention, and updating composite of the D–KEFS from the independent analyses

Updating

Finally, inattention, anxiety, and their interaction were explored as predictors of updating performance. The overall model was significant, F (3, 138) = 4.25, $p < .01$, Adjusted $R^2 = .07$, where greater inattentive ($\beta = -.23$, $t(138) = -2.72$, $p < .01$), but not anxiety, symptoms were predictive of worse updating performance. The interaction of inattention and anxiety ($\beta = -.23$, $t(109) = -2.51$, $p < .05$) was also found to improve prediction of updating performance beyond inattention and anxiety alone, $\Delta R^2 = .05$, $p < .05$. Simple slopes analyses revealed that for individuals high in anxiety (i.e., one standard deviation above the mean), inattention was negatively associated with updating ($\beta = -.47$, $t(138) = -3.57$, $p < .01$), whereas this relationship was not significant for individuals low in anxiety (i.e., one standard deviation below the mean) ($\beta = -.01$, $t(138) = -.06$, $p > .05$). See Fig. 2.

Independent models: hyperactivity/impulsivity, anxiety, and their interaction: predicting executive functioning domains

Inhibition

In parallel, hyperactivity/impulsivity, anxiety, and their interaction were examined as predictors of executive functioning domains: inhibition, shifting, and updating (respectively). First, hyperactivity/impulsivity, anxiety, and their interaction were examined as predictors of inhibition. The model was significant, F (2, 137) = 3.21, $p < .05$, Adjusted $R^2 = .04$, where greater hyperactivity/impulsivity ($\beta = -.18$, $t(137) = -2.10$, $p < .05$)., but not anxiety, symptoms were associated with worse inhibition performance. The addition of the interaction of hyperactivity/impulsivity and anxiety in the second step was not significant ($p > .05$).

Shifting

A similar pattern was observed when predicting shifting performance.

The model was significant, F (2, 108) = 3.21, $p < .05$, Adjusted $R^2 = .04$, with greater hyperactivity/impulsivity ($\beta = -.21$, $t(108) = -2.17$, $p < .05$), but not anxiety, symptoms were associated with worse shifting. The addition of the interaction of hyperactivity/impulsivity and anxiety in the second step was not significant ($p > .05$).

Updating

Finally, hyperactivity/impulsivity, anxiety, and their interaction were explored as predictors of updating performance. The overall model was significant, F (3, 137) = 2.83, $p < .05$, Adjusted $R^2 = .04$, despite no main effects being significant. The interaction between hyperactivity/impulsivity and anxiety symptoms ($\beta = -.22$, $t(137) = -2.56$, $p < .05$), however, was predictive of worse updating performance, which significantly improved model fit, $\Delta R^2 = .04$, $p < .05$. Simple slopes analyses revealed that for individuals high in anxiety (i.e., one standard deviation above the mean) hyperactivity/impulsivity was negatively associated with updating ($\beta = -.54$, $t(137) = -3.64$, $p < .01$). This relationship was not significant for individuals low in anxiety (i.e., one standard deviation below the mean) ($\beta = -.05$, $t(137) = -.38$, $p > .05$). See Fig. 3.

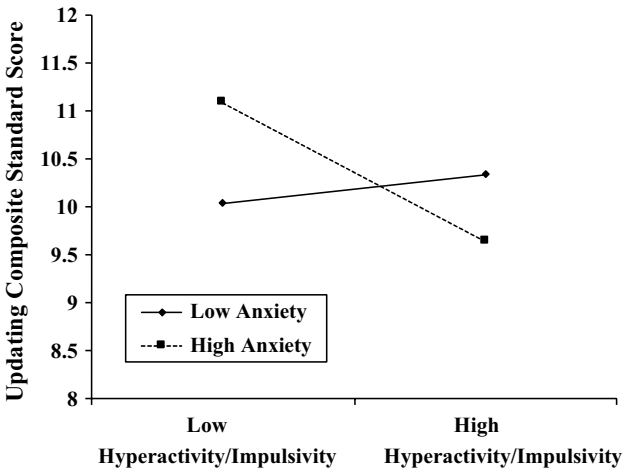

Fig. 3 Interaction between anxiety, hyperactivity/impulsivity, and updating composite of the D–KEFS from the independent analyses

Full model: inattention, hyperactivity/impulsivity, and their interactions with anxiety: predicting executive functioning domains

Inhibition

The overall model, F (3, 127) = 3.50, $p < .05$, Adjusted $R^2 = .05$, significantly predicted inhibition performance. Specifically, inattention ($\beta = -.21$, $t(127) = -2.05$, $p < .05$), but not anxiety nor hyperactivity/impulsivity, significantly predicted inhibition; greater inattentive symptoms were associated with worse performance. The interactions of inattention and anxiety, as well as hyperactivity/impulsivity and anxiety were not found to be significant predictors.

Shifting

The model predicting shifting was significant, F (6, 105) = 2.66, $p < .05$, Adjusted $R^2 = .08$, where the main effect of inattention ($\beta = -.27$, $t(105) = -2.43$, $p < .05$), but not anxiety nor hyperactivity/impulsivity, significantly predicted worse shifting performance. The interaction of inattention and anxiety ($\beta = -.31$, $t(105) = -2.56$, $p < .05$) improved prediction of shifting beyond inattention, hyperactivity/impulsivity, and anxiety alone, $\Delta R^2 = .06$, $p < .05$. Simple slopes analyses revealed that for the individuals high in anxiety (i.e., one standard deviation above the mean), inattention was negatively associated with shifting ($\beta = -.60$, $t(105) = -3.30$, $p < .01$). However, this relationship was not significant for individuals low in anxiety (i.e., one standard deviation below the mean; $\beta = .06$, $t(105) = .43$, $p > .05$). See Fig. 4.

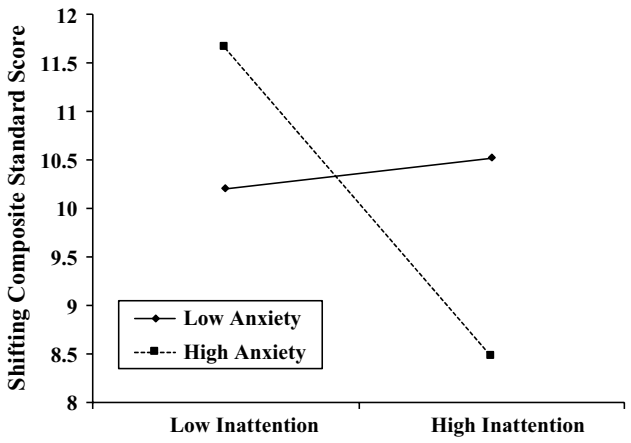

Fig. 4 Interaction between anxiety, inattention, and shifting composite of the D–KEFS from the full model

Updating

The overall model, F (6, 134) = 3.20, $p < .05$, Adjusted $R^2 = .09$, significantly predicted updating performance. Specifically, inattention ($\beta = -.24$, $t(134) = -2.29$, $p < .05$), but not anxiety, significantly predicted updating, with greater inattentive symptoms associated with worse performance. The interactions of inattention and anxiety, as well as hyperactivity/impulsivity and anxiety were not significant.

Discussion

ADHD is associated with EF deficits, though studies are mixed as to what degree these EF deficits differ across subtypes varying in severity of inattentive and hyperactivity/impulsivity symptoms. Additionally, ADHD and anxiety are highly comorbid, but prior studies have focused on diagnostic groups when examining differences in group EF performance. The purpose of the current study was to explore how anxiety may moderate the effect of different symptom dimensions of ADHD (i.e., inattention and hyperactivity/impulsivity) on domains of EF (i.e., inhibition, updating, and shifting).

Results of our independent models provided partial support for our hypotheses that anxiety would negatively moderate the relationship between inattention and both shifting and updating. Low levels of anxiety had no effect on youths' shifting and updating performance in those with low or high inattention. On the other hand, high levels of anxiety was associated with worse shifting and updating performance for youth with high levels, but not low levels, of inattention. A similar pattern was found for hyperactivity/impulsivity symptoms but only when predicting updating (but not shifting). These findings are generally in line with past research that has relied on diagnostic group differences. As noted, youth with ADHD and comorbid anxiety often have impaired updating (Jarrett et al. 2012; Pliszka 1989; Skirbekk et al. 2011; Tannock 2009; Tannock et al. 1995). Furthermore, those with ADHD and anxiety (respectively) demonstrate deficits in shifting (Emerson et al. 2005; Visu-Petra et al. 2014; Toren et al. 2000; see Yurtbaşı et al. 2018).

Though hyperactivity/impulsivity, when examined separately from inattention, had associations with domains of executive functioning (i.e., updating), when examined jointly with inattention, only inattention was a unique predictor of shifting performance. Inattention uniquely predicted poorer performance in all three domains of executive functioning. However, anxiety only significantly moderated the relationship between inattention and youths' shifting performance, with a pattern of results similar to those of the independent models. This finding of a greater role of inattentive symptoms in executive functioning is consistent with prior work

using categorical diagnoses of ADHD, where greater deficits for those with ADHD-I versus those with ADHD-HI has been observed (Bedard et al. 2003; Chhabildas et al. 2001; Pitcher et al. 2002; Schmitz et al. 2002). It is also possible that our results reflect that anxiety does not have a relationship (i.e., as a main effect or moderator) with inhibition nor updating in our community sample.

Theorists have begun to suggest that EF weakness may be particularly relevant to inattention, rather than hyperactivity/impulsivity (e.g., Sonuga-Barke 2002). If so, EF deficits could be masked by past research seldom analyzing these two partially separable behavioral domains independently. This led Nigg et al. (2005) to suggest that it is theoretically important to clarify whether EF deficits are more strongly related to inattention than hyperactivity/impulsivity. ADHD subtype comparisons can be limited, as persons with similar symptoms could get put into different subtype groups (e.g., an individual with six inattentive symptoms but one hyperactivity/impulsivity symptom below threshold would be placed in the ADHD-I group versus a similar individual with six inattentive symptoms but one more hyperactivity/impulsivity symptom, who would be placed in the ADHD-C group).

Given our findings that EF is impaired when youth have a combination of high ADHD/high anxiety symptoms has important clinical, research, and real-world implications. First, our results have the potential to provide clinicians and evaluators with a more thorough understanding of how these often-co-occurring symptoms may interact to further impair EF functioning. For example, youth both high in inattention and anxiety may be at increased risk for outcomes related to worse EF or emotional problems (see Muris et al. 2011). Moreover, ADHD interventions sometimes try and target EF problems, which may be especially worth targeting when a clinician is aware of their client's comorbid ADHD and anxiety symptoms (Halldorsdottir and Ollendick 2014). It is likely that increased EF deficits may moderate treatment outcome. From a research perspective, we provide novel evidence by demonstrating the importance of examining both ADHD symptom clusters and anxiety independently, as well as collectively, when predicting EF performance. Our results suggest that future research may benefit by examining the relationship among all three of these variables, dimensionally, as they are highly comorbid and may provide a better understanding of EF.

Future research should continue to explore the associations between and among anxious, inattention, and hyperactivity/impulsivity symptoms, as well as with EF, using various measures of inhibition, updating, and shifting (in both clinical and nonclinical samples) to continue to elucidate this relationship. Importantly, however, future research will likely benefit from parsing out the differential effects of the various symptoms of ADHD. While past research has generally used samples of youth diagnosed with ADHD, it is likely that youth within these samples have vastly different levels of inattention, hyperactivity, impulsivity, as well as anxiety. Therefore, it may behoove future researchers to examine clinical samples from a dimensional symptom, as opposed to a categorical, perspective.

Limitations

The current study has a number of limitations that should be addressed. First, the sample was relatively small, homogenous, and comprised of a nonclinical sample from a publicly available dataset. Further replication is needed in a larger, more diverse sample. Additionally, our sample included youth of a broad age range. Given the dearth of the literature examining this important topic across all three domains of EF, we felt it was important to first step to demonstrate this relationship in a broad sample of youth. However, future research should examine whether this relationship differs across various stages of development. Finally, we did not control for the effects of comorbid disruptive behaviors (e.g., oppositional behavior, etc.), and therefore it is currently unknown how incorporating these symptoms would affect our findings. As previously mentioned, future researchers should look to examine the effects of ADHD symptomatology from a dimensional perspective when examining their relationship with EF and anxiety.

Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

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

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

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