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Does Anxiety Enhance or Hinder Attentional and Impulse Control in Youth With ADHD? An ERP Analysis

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Abstract

Objective: Youth with ADHD and comorbid anxiety (ADHD+ANX) experience increased social and academic impairment compared with youth with ADHD without anxiety (ADHD). Group differences in attentional and impulse control may underlie this increased impairment. Examination of group differences using behavioral measures of attentional and impulse control has yielded inconsistent findings. This study explored group differences using event-related potentials (ERPs), which provide neural information concerning early information processing. **Method:** ERPs (early frontal positivity [EFP], N2) were collected while youth aged 11 to 17 with ADHD (n = 31) and ADHD+ANX (n = 35) completed a visual and an auditory computer task. **Results:** Compared with the ADHD group, the ADHD+ANX group exhibited larger N2 amplitudes to no-go stimuli and larger EFP amplitudes to target auditory stimuli, with variable attention allocation to nontarget stimuli. **Conclusion:** The addition of anxiety to ADHD appears to alter early attentional processing, which may be an important aspect of this comorbidity. *(J. of Att. Dis. XXXX; XX(X) XX-XX)*

Keywords

ADHD, anxiety, attentional control, impulse control, event-related potentials

Introduction

ADHD is the most common neurodevelopmental disorder, affecting approximately 3.5% of youth worldwide (Polanczyk, Salum, Sugaya, Caye, & Rohde, 2015). Anxiety commonly co-occurs with ADHD, with estimates ranging from 27% (Spencer, Biederman, & Wilens, 1999) to 40% (Tannock, 2009). The co-occurrence of anxiety is important to consider given that youth with the co-occurring condition exhibit greater social (Bowen, Chavira, Bailey, Stein, & Stein, 2008; Mikami, Ransone, & Calhoun, 2011), cognitive (Pliszka, 1989, 1992), and academic (Jensen et al., 2001) impairment than youth with ADHD or anxiety alone. Differences in attentional and impulse control, two central areas of impairment in ADHD, have been suspected to contribute to this pattern of heightened impairment (Manassis, Tannock, & Barbosa, 2000; Mayes & Calhoun, 2007; Pliszka, 1989, 1992; Sørensen, Plessen, Nicholas, & Lundervold, 2011; Vloet, Konrad, Herpertz-Dahlmann, Polier, & Günther, 2010). Attentional control refers to the ability to effectively orient and sustain attention while filtering out irrelevant stimuli (Derakshan & Eysenck, 2009), whereas impulse control reflects the ability to actively suppress, interrupt, or delay an action (Manassis et al., 2000).

The strength and the direction of the impact of co-occurring anxiety on attention and impulse control in ADHD remain unclear. Studies employing behavioral and questionnaire measures of attentional and impulse control have yielded mixed findings (Manassis et al., 2000; Pliszka, 1989; Schatz & Rostain, 2006; Vloet et al., 2010). For example, Pliszka (1989) found that anxiety interacts with ADHD to further impair attentional control. In contrast, Sørensen et al. (2011) and Vloet et al. (2010) have shown an attention-enhancing effect of anxiety in the context of ADHD. A pattern of inconsistent findings also exists for the impact of anxiety on impulse control in ADHD. Some studies have suggested that anxiety enhances impulse control (Manassis et al., 2000; Pliszka, 1989, 1992; Sørensen et al.,

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2011), whereas others have found no significant group differences (Korenblum, Chen, Manassis, & Schachar, 2007; Newcorn et al., 2001; Vloet et al., 2010).

Similar patterns of variable findings are noted in the literature that examines the impact of anxiety alone on attentional control in youth. For example, Muris, van der Pennen, Sigmond, and Mayer (2008) found a significant negative relation between high self-reported trait anxiety and attentional control, however, these self-reports were unrelated to behavioral measures. Similarly, Mogg and colleagues (2015) found that children with clinical levels of anxiety showed impaired attentional control compared with controls. In contrast, Günther, Holtkamp, Jolles, Herpertz-Dahlmann, and Konrad (2004) did not find any deficits in attentional control or memory function in youth with clinical levels of anxiety when compared with youth with depression as well as controls. It is possible that mixed findings across anxiety and ADHD and comorbid anxiety (ADHD+ANX) may be due to behavioral performance being affected by a number of variables, beyond attentional and impulse control.

The use of neural measures that are able to detect the earliest differences in attention allocation may assist in clarifying the impact of comorbid anxiety on attentional and impulse control in ADHD. Event-related potentials (ERPs) are manifestations of neural activity that can be used to reflect the allocation of attentional resources in contexts requiring attentional and/or impulse control (e.g., Dimoska, Johnstone, Barry, & Clarke, 2003; Lackner, Santesso, Dywan, Wade, & Segalowitz, 2013). ERPs are presumably less influenced by an individual's response strategy compared with self-report or behavioral measures (Luck, 2014) and, therefore, may be more sensitive to underlying neural processes that differentiate various groups than behavioral measures used in the previous research (Harms, Martin, & Wallace, 2010).

ERPs have been used to examine attentional and impulse control in youth with ADHD only and anxiety only, yielding findings that suggest a more consistent attention-enhancing impact of anxiety. This literature is reviewed below to shed light on the specific ERP components reflective of attentional and impulse control and their findings for ADHD and anxiety samples. There appear to be no ERP studies, however, that have examined comorbid ADHD and anxiety, or have specifically explored whether anxiety may enhance attentional and impulse control in youth with ADHD.

ERP Components Reflective of Attentional Control

N1. The N1 is a component elicited by an auditory stimulus that is both detected and attended to (Naatanen & Picton, 1987; Ritter, Simson, Vaughan, & Friedman, 1979). It is observed at fronto-central sites approximately 100 ms after the stimulus onset (Luck & Kappenman, 2012). Youth with ADHD exhibit smaller N1 amplitudes to target stimuli than youth without ADHD (Satterfield, Schell, & Nicholas, 1994). In contrast, an opposite pattern has been found in youth with anxiety; youth with higher self-reported ratings of anxiety have significantly larger N1 amplitudes to target tones compared with youth with lower ratings of anxiety (Hogan, Butterfield, Phillips, & Hadwin, 2007). These results suggest that anxiety, when experienced in the context of ADHD, may enhance attention allocation to target over nontarget stimuli.

P3b. The P3b is produced when attending to and classifying visual or auditory stimuli (Luck, 2014). Similar to the early frontal positivity (EFP; see below) and the N1, youth with ADHD exhibit smaller P3b amplitudes to target stimuli compared with controls without ADHD (Satterfield et al., 1994). Research has seldom explored P3b activity in youth with anxiety. The limited research does suggest, however, that similar to research examining the N1, typically developing youth reporting a larger number of anxiety symptoms produce larger P3b amplitudes to target stimuli (Daruna, Rau, & Strecker, 1991).

EFP. The EFP is a newly described ERP component that is observed using a selective auditory attention task, in which participants have to attend to specific tones while ignoring others. The EFP is a broad positivity observed from approximately 50 to 150 ms poststimulus, and is likely not a P50 or P1-like component (Lackner et al., 2013). Although they do not refer to it as an EFP, Jonkman et al. (1997) found that positive-going amplitudes in the EFP time range were significantly smaller for attended target (AT) tones in youth with ADHD compared with age-matched controls without ADHD. Lackner et al. (2013) found that EFP amplitude varied by level of executive function challenge in everyday life (a common area of cognitive dysfunction in ADHD), with larger EFP amplitudes to unattended target (UT) tones compared with target tones in youth with greater executive function challenge. Taken together, similar to findings on the N1 and P3b, these findings suggest that youth with ADHD (or executive functioning challenges that are similar to those seen in ADHD) may allocate more attention to "to be ignored" stimuli than target stimuli. Although no studies have examined the EFP in an anxiety sample, the N1 and P3b suggest that anxiety may enhance attention allocation to target stimuli.

ERP Components Reflective of Impulse Control

ERPs, specifically the no-go N2 and P3, can also be used to assess attention allocation when impulse control (a behavioral response) is required.

N2. The N2 is observed approximately 200 to 400 ms after a participant is presented with a stimulus. Its effect can be observed in go/no-go tasks, in which participants are required to press a button as fast as possible to frequent "go" stimuli, and withhold a response to a rare "no-go" stimulus. The latter is demarcated in a variety of ways, such as with a specific stimulus or in some cases with a repetition of a stimulus. It is larger when participants successfully inhibit their response to the rare no-go stimuli, and smaller when they correctly respond to the go stimuli (Falkenstein, Hoormann, & Hohnsbein, 1999). When stimuli require withholding a response, N2 amplitudes are significantly smaller in youth with ADHD relative to youth without ADHD (Dimoska et al., 2003; Johnstone, Barry, Markovska, Dimoska, & Clarke, 2009; Liotti, Pliszka, Higgins, Perez, & Semrud-Clikeman, 2010), whereas an opposite pattern of results has been found in youth with anxiety (Hum, Manassis, & Lewis, 2013a, 2013b). For example, using a computerized go/no-go task, Hum et al. (2013a) found that youth with anxiety had significantly larger no-go N2 amplitudes than youth without anxiety. They also found that youth with anxiety exhibited similar N2 amplitudes to the two trial types, whereas control youth without anxiety exhibited larger amplitudes during the no-go condition compared with the go condition (Hum et al., 2013a). It is, therefore, possible that the addition of anxiety to ADHD may be associated with larger N2 amplitudes to no-go stimuli; however, differences in amplitudes to go and no-go stimuli may be minimal.

P3. The P3 is observed approximately 300 to 500 ms post stimulus onset (Luck, 2014). Unlike its generation in tasks measuring selective auditory or visual attention, it has been proposed that the P3 elicited during a go/no-go task reflects monitoring of the outcome of the inhibitory process during correct inhibition trials (Liotti, Pliszka, Perez, Kothmann, & Woldorff, 2005). Like the N2, P3 amplitudes are larger when participants successfully inhibit their response to the infrequent no-go stimuli, and smaller when they correctly respond to the go stimuli (Falkenstein et al., 1999). Furthermore, P3 amplitudes to no-go stimuli are significantly smaller in youth with ADHD relative to youth without ADHD (Groom et al., 2010; Liotti et al., 2005; Liotti et al., 2010). Similar to the N2, anxiety has been associated with the opposite effect (Sehlmeyer et al., 2010), suggesting that ADHD+ANX may be associated with larger P3 amplitudes to no-go stimuli than ADHD alone.

The Present Study

We examined whether the addition of anxiety to ADHD is associated with differences in attentional and impulse control using ERP measures. Given that ERPs measure the earliest stages of information processing, it was hypothesized that this method may aid in clarifying the mixed findings in the literature using behavioral measures of attentional and impulse control. Based on previous research with ADHD without anxiety and anxiety-only samples, we predicted that the addition of anxiety in youth with ADHD would result in larger amplitudes to target stimuli, reflecting enhanced attentional processing. A secondary objective was to explore the timing of any group differences that might emerge. ERP components occur at different stages of information processing, and it is possible that anxiety may differentially affect components depending on their timing. This temporal relation has not been routinely explored in the ADHD and anxiety literature to date and, thus, is exploratory in nature. Finally, this study sought to explore differences across type of stimuli (target, nontarget), to see whether anxiety has a specific pattern of impact depending on type of stimuli. Again, given the limited research in this area, no specific predictions were made.

Method

Participants

This study used the baseline data collected as part of a larger ongoing treatment trial of a mental health program for youth with learning disabilities and co-occurring mental health issues. Eighty-four parents and youth independently completed the *Mini International Neuropsychiatric Interview for Children and Adolescents* (*MINI-KID;* Sheehan et al., 1998), a structured diagnostic interview for children and adolescents (ages 6-18 years), to confirm the presence of ADHD and anxiety, as well as ADHD subtype. Data from all youth who met the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.; *DSM-IV*; American Psychiatric Association, 1994) criteria for ADHD+ANX or ADHD without anxiety by parent or youth report were included in this study. Participants included 67 (n = 33 ADHD+ANX, n = 34 ADHD without anxiety) English-speaking youth aged 11 to 17. Given that 70% of youth with ADHD have a learning disability (Mayes, Calhoun, & Crowell, 2000), all youth in the study had a previously diagnosed learning disability (i.e., average levels of cognitive ability with significantly lower than expected levels of academic achievement and challenges in at least one area of information processing; Learning Disabilities Association of Ontario, 2002). The presence of the learning disability was verified based on a review of the participant's past psychoeducational assessment (completed outside of this study). Participant demographic information is displayed in Table 1. Significant group differences were found for age, with ADHD without anxiety participants being approximately 1 year younger (M = 12.35, SE = 0.11) than participants with ADHD+ANX (M = 13.36, SE = 0.34), $t(65) = 2.86$, $p = .006$. Participants with

Table 1. Demographic Information.

Group	ADHD	ADHD+ANX
WISC-IV verbal comprehension	M = 69.04, SE = 5.47	M = 64.67, SE = 5.63
Age (in years)	M = 12.35, SE = 0.11*	M = 13.36, SE = 0.34*
ADHD subtype		
Inattentive	20	19
Hyperactive/impulsive	2	0
Combined	12	16
Gender		
Male	29	26
Female	3	7
Stimulant medication		
Takes medication	13	12
Does not take medication	19	21
Frequency of specific comorbid diagnoses		
Depression	6	13
Oppositional defiant/ conduct disorder	9	14
Conduct disorder	1	1
Tic disorder	0	4
Autism	4	7
Mean number of additional diagnoses	0.59 (SE = 0.11)	1.11 (SE = 0.15)

Note. ANX = comorbid anxiety; WISC-IV = Wechsler Intelligence Scale for Children (Wechsler, 2003).
*p < .05.

ADHD+ANX had significantly more comorbid diagnoses (above and beyond anxiety) than participants with ADHD without anxiety, $t(67) = 2.77$, $p = .007$. No significant group differences were found for cognitive ability (verbal comprehension), gender, ADHD subtype, or medication status. Household income ranged from less than Can$25,000 to more than Can$200,000, with no significant differences between groups.

Procedure

Youth and their parents attended a 3-hr testing session at Ryerson University. Electroencephalography (EEG) activity was recorded using the International 10/20 BioSemi ActiveTwo EEG (BioSemi, 2007) system at a sampling rate of 512 Hz with 0.1 to 100 Hz analog filtering while youth completed a series of computer tasks. Participants received Can$25 for their participation. Ethical approval for the project was obtained from the Ryerson University Research Ethics Board.

Measures

Selective auditory attention task. The dual channel selective auditory attention task employed by Lackner and colleagues (2013) was slightly modified and used to examine ERP indices of attentional control. The stimuli consisted of two 200 ms tone types presented at an interstimulus interval of 600 to 800 ms using two computer speakers located to the left and right side of the participant. Participants were asked to respond by pressing a button on a keypad when they heard the target tone in the attended side, and not to respond otherwise. The test trials included four blocks of 200 trials each. Trial breakdown across the entire task was as follows: 48 trials of 2,000 Hz tones presented to the attended side (ATs), 48 trials of 2,000 Hz tones presented to the unattended side (UTs), 352 trials of 1,000 Hz tones presented to the attended side (attended nontargets; ANTs), and 352 trials of 1,000 Hz tones presented to the unattended side (unattended nontargets; UNTs).

Group differences in accuracy (defined as the percentage of accurate responses to ATs), and errors (defined as the percentage of false positive responses to ANTs) were also measured. Eleven participants responded incorrectly to more than 80% of one trial type (e.g., made false alarms to 80% of ANTs, or failed to respond to 80% of ATs). These participants were not included in the final sample as their data may reflect inadequate understanding of the task instructions.

Go/no-go task. This task was adapted from a task developed by Garavan, Ross, and Stein (1999). Participants were required to press a button as fast as possible whenever a character flashed on the computer screen ("go" trials), and withhold a second response if the character presented itself twice in a row ("no-go" trials). Error feedback was provided following incorrect responses, omitted responses, and late responses. Points, which were displayed on a thermometer image on the screen after every 20 trials, were added for correct no-go responses and deducted for response errors on both go and no-go trials. Three blocks of structurally identical trials were presented, each consisting of 200 trials (including 66 no-go trials in pseudorandom sequence). In addition to N2 and P3 components for correct no-go trials, group differences in omission and commission errors, as well as response times, were measured. One participant responded to almost all no-go stimuli, suggesting a lack of understanding or attention to task instructions. This participant was not included in the final sample.

EEG Data Processing

EEG data recorded at 64 scalp sites were re-referenced offline to the average of all sites, filtered (1-30 Hz), and all independent components representing eye movements, heart rate, or other muscle activity were removed using independent component analysis (ICA; Delorme, Sejnowski, & Makeig, 2007). Data were then manually pruned to exclude any excessively noisy channels or artifacts that the ICA failed to remove. For both, the selective auditory attention and go/no-go tasks, the data were then projected back to the scalp channels. Data were then segmented to stimulus-locked epochs for correctly responded to target and nontarget stimuli.

Following this, data were averaged into ERP segments of 1,000 ms for AT, ANT, UT, and UNT correctly responded to (800 ms poststimulus and 200 ms prestimulus baseline). This created averaged overall waveforms for each trial type for each participant (i.e., correct AT, ANT, UT, and UNT trials; correct go and no-go trials). These data were then scored for peak amplitude and latency at Fz, FCz, and Cz by a coder blind to participant characteristics. The site at which the amplitude was maximal for the full sample (Fz for all components) was used in analyses.

Results

Behavioral Responses

Selective auditory attention task. A MANOVA was completed to examine the impact of group (ADHD, ADHD+ANX) on accuracy in each condition (AT, UT, ANT, UNT). Significant group differences were found for UT, with the average response rate for UT being greater for participants with ADHD+ANX than ADHD, $F(1, 54) = 4.25$, $p = .04$. No significant group differences were found for AT, ANT, or UNT. Average response rate for UT was not significantly related to the amplitude or latency of any of the ERP components examined.

Go/no-go task. A MANOVA was completed to examine the impact of group (ADHD, ADHD+ANX) on accuracy in each condition (go, no-go). Significant group differences were found for no-go corrects, with the average accuracy being greater for participants with ADHD+ANX than ADHD, $F(1, 65) = 5.63$, $p = .02$. No significant group differences were found for go corrects, go errors, or reaction time. No-go corrects were not significantly related to the amplitude or latency of any of the ERP components examined.

ERP Measures of Attentional Control

A series of factorial repeated-measures ANOVAs were completed to examine the impact of group (ADHD vs. ADHD+ANX) and condition (AT, UT, ANT, UNT) on each of the ERP components of interest (EFP, N1, P3). Where Mauchly's test indicated that the assumption of sphericity had been violated, the degrees of freedom were corrected using Huynh–Feldt estimates of sphericity. Correlational analyses indicated that age was significantly related to the amplitude of the EFP in the ANT ($r = -.32$) and UNT ($r = -.33$) conditions; latency of the EFP in the ANT ($r = -.36$), UT ($r = -.27$), and UNT ($r = -.35$) conditions; and amplitude of the P3 ($r = -.26$). Number of diagnoses was not related to the amplitude or latency of any of the ERP components of interest. Given the relation between the EFP component at age, age was included as a covariate in analyses.

Examining performance across all conditions, a trend toward a significant Condition × Group interaction was found for EFP amplitude, Wilks's $\lambda = .88$, $F(2.29, 50) = 2.17$, $p = .10$. Given this trend and that previous research using this paradigm has only compared AT and UT conditions, two additional repeated-measures ANOVAs were completed to further explore group differences for AT–UT (i.e., target tone, variable side) and AT–ANT (target side, variable tone). A significant Group × Condition (AT–ANT) interaction was found, such that participants with ADHD+ANX had larger EFP amplitudes to ATs compared with ANTs (Wilks's $\lambda = .92$, $F(1, 54) = 4.77$, $p = .03$), with a post hoc paired-sample t test revealing that this difference was significant, $t(26) = 4.50$, $p < .001$. This significant Group × Condition interaction held when controlling for age, Wilks's $\lambda = .92$, $F(1, 52) = 4.68$, $p = .03$. No significant AT–ANT amplitude difference was found for the ADHD group, $t(28) = -0.08$, $p = .93$. Amplitudes for AT–UT did not significantly differ by group. See Figure 1 for grand-averaged ERP waveform for all stimuli conditions.

No significant Group × Condition interactions were found for EFP latency, or the N1 and P3b amplitude or latency.

Impulse Control

A series of factorial repeated-measures ANOVAs were completed to examine the impact of group (ADHD vs. ADHD+ANX) and condition (go, no-go) on each of the ERP components of interest (N2, P3). Correlational analyses indicated that age was only significantly related to the amplitude of the N2 in the go condition ($r = .28$). Number of diagnoses was not related to the amplitude or latency of any of the ERP components of interest. Given the relation between the N2 component at age, age was examined as a covariate in analyses.

A significant Group × Condition interaction was found for N2 amplitude, Wilks's $\lambda = .94$, $F(1, 63) = 3.84$, $p = .05$. Contrary to expectation, larger N2 amplitudes were found in the go compared with no-go conditions for both groups; however, the ADHD+ANX group showed larger amplitudes to no-go stimuli than the ADHD group. Post hoc paired-sample t tests revealed that the go/no-go amplitude difference was significant for both the ADHD, $t(30) = -5.34$, $p < .0001$, and ADHD+ANX, $t(33) = -3.65$, $p = .001$, groups. This significant Group × Condition interaction held when controlling for age, Wilks's $\lambda = .94$, $F(1, 62) = 3.87$, $p = .05$. See Figure 2 for grand-averaged ERP waveform for go and no-go conditions.

No significant Condition × Group interactions were found for N2 latency, or P3 amplitude or latency.

Discussion

The present study explored the impact of anxiety on attentional and impulse control in youth with ADHD using

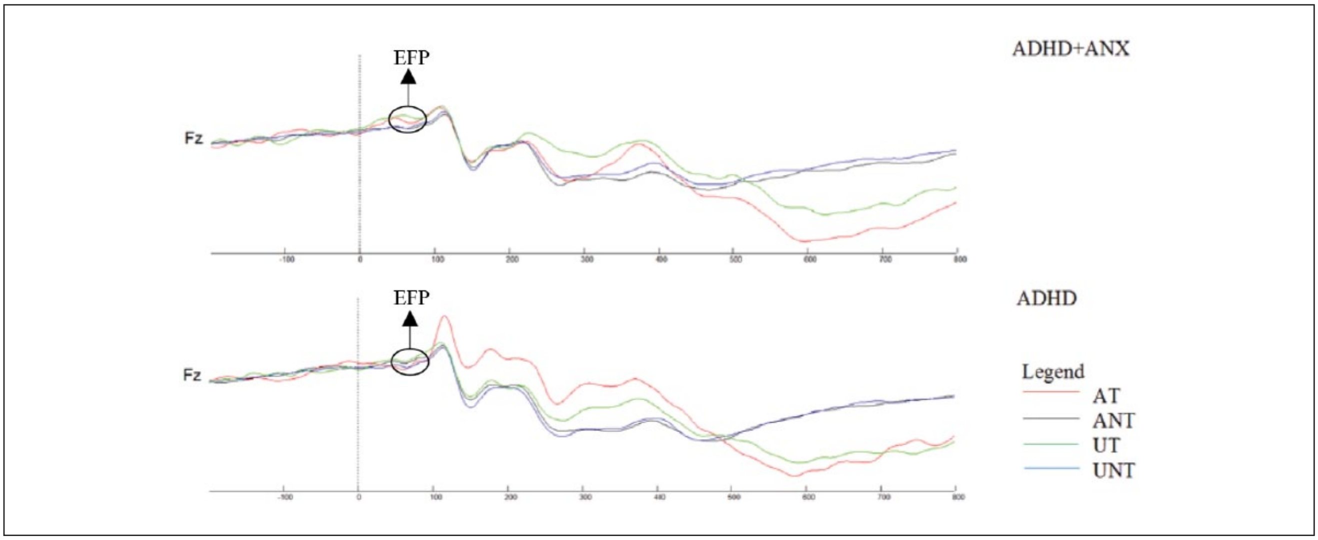

Figure 1. Selective auditory attention task grand-averaged waveforms of youth with ADHD+ANX and ADHD.
Note. ANX = comorbid anxiety.

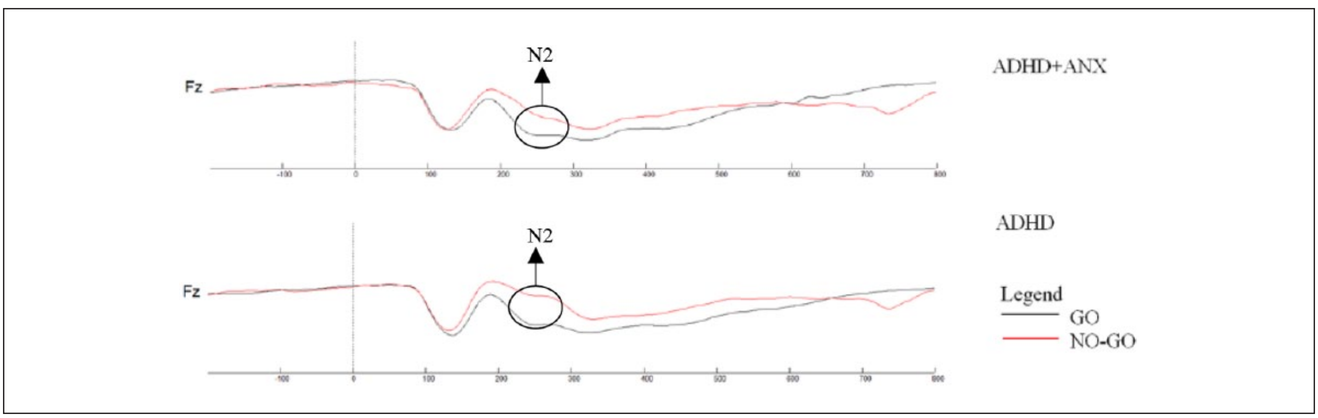

Figure 2. Go and no-go grand-averaged waveforms of youth with ADHD+ANX and ADHD.
Note. ANX = comorbid anxiety.

ERPs. Overall, results suggest that the addition of anxiety is associated with significant differences in attentional and impulse control, with ERP indices suggesting that anxiety enhances attention allocation during tasks in which attentional and/or impulse control are required.

In terms of attentional control, youth with ADHD+ANX exhibited larger EFP amplitudes to auditory target stimuli compared with some, but not all, nontarget stimuli (ANT only), whereas no significant differences in amplitude were indicated between target and nontarget stimuli in the ADHD group. The finding of increased attentional control in the ADHD+ANX group compared with the ADHD group is consistent with previous studies (Rodríguez, González-Castro, García, Núñez, & Alvarez, 2014; Vloet et al., 2010), that found that youth with ADHD+ANX exhibited better performance than youth with ADHD without anxiety on behavioral tasks requiring divided, selective, and sustained attention. Past research using the selective auditory attention task with samples with ADHD (or characteristics of ADHD) has found that youth with ADHD allocate more attentional resources in response to nontargets than to targets. In this study, we found that youth with ADHD+ANX allocated attention differentially depending on characteristics of the stimuli. Specifically, they appeared to allocate attentional resources based on tone (larger amplitudes for target tone, regardless of side, smaller amplitudes for nontargets). In contrast, amplitudes did not significantly differ based on stimuli characteristics for the ADHD group. This pattern of anxiety-enhancing attentional control may be explained, in part, by attentional biases.

Attentional biases toward threat or negative stimuli are well documented for anxious youth (e.g., Puliafico &

Kendall, 2006). Richards, Benson, Donnelly, and Hadwin (2014) theorized that attentional biases toward threat in anxiety result in an enhanced ability to selectively attune to and prioritize the processing of threatening stimuli while filtering out task-irrelevant, nonthreatening stimuli. Specifically, the addition of anxiety in youth allowed for the enhanced processing of task-relevant stimuli (ATs) while filtering out nontarget tones (ANTs). Although ATs are not “threatening” per se, they do indicate to youth that a specific response is required. In youth with anxiety who may be worried about task performance (Eysenck & Calvo, 1992), the processing of information relating to type of tone may be prioritized (with attentional resources heightened) over other types of information, as they serve to warn that the execution of a correct response is required. However, anxiety impairs performance when attention is oriented toward threatening stimuli that is not relevant to task performance (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007). For example, in studies that employ the emotional Stroop task, individuals with anxiety are slower to name a color presented with an emotionally charged word, which suggests that orienting attention to threatening stimuli at the expense of task-relevant stimuli negatively affects performance (Bar-Haim et al., 2007; Derakshan & Eysenck, 2009). This parallels our behavioral findings, which demonstrate that when task-irrelevant threats (i.e., UTs) are incorporated into the task paradigm, youth with ADHD+ANX demonstrate significantly more errors than youth with ADHD without anxiety.

Turning to impulse control, N2 amplitudes were significantly larger in the go rather than no-go condition across both groups. This is the reverse pattern from what would be expected. Although rare, a reverse pattern of results has been demonstrated in both youth with ADHD (Groom et al., 2010) and youth with anxiety (Hum et al., 2013a). Notably, Groom et al. (2010) found that their reward condition was associated with larger no-go N2 amplitudes in youth with ADHD. It is possible that the go/no-go task used in the current study was not associated with large enough rewards, therefore, future research should explore whether greater rewards for correct responses are associated with larger no-go than go N2 amplitudes in youth with ADHD.

Despite this pattern, a significant Group × Condition interaction was found for N2 amplitudes, such that the ADHD+ANX group exhibited larger N2 amplitudes during no-go trials compared with the ADHD group, with no significant group differences for the go trials. Behaviorally, the ADHD+ANX group also demonstrated more correct inhibitions compared with the ADHD group. Enhanced impulse control in the ADHD+ANX group is consistent with previous research demonstrating that N2 amplitudes for tasks requiring impulse control are significantly larger in youth with anxiety compared with youth without anxiety (Hum et al., 2013a). These findings are also consistent with previous research using behavioral, self-, teacher-, and/or parent-report measures of impulsivity that demonstrate that the addition of anxiety in youth with ADHD results in fewer challenges with impulsivity (Manassis et al., 2000; Pliszka, 1989, 1992). The impulse-enhancing effect of anxiety can be understood using Eysenck and Calvo’s (1992) processing efficiency theory. This theory suggests that although self-preoccupation and worry about performance will impair the execution of challenging tasks in individuals with anxiety (by inciting high levels of state anxiety), the desire to do well may serve to motivate and enhance performance in individuals with ADHD+ANX during simple tasks, which incite low levels of state anxiety, thus resulting in better impulse control (Rodríguez et al., 2014). The go/no-go task could be considered a simple task with just one stimulus characteristic to vigilantly attend to (i.e., a duplicate stimuli), and perhaps did not incite high levels of state anxiety. Therefore, the addition of anxiety in youth with ADHD may have resulted in a desire to perform well, allowing youth with ADHD+ANX to demonstrate enhanced impulse control behaviorally and to allocate increased attentional resources during the current study’s simple go/no-go task. It is also possible that youth with ADHD+ANX perceived the task to be easy, inciting low levels of state anxiety, allowing for increased engagement and focus on the study’s task.

In contrast, anxiety may negatively affect attentional and impulse control during more challenging tasks. In the present study, the selective auditory attention task could be conceived as a more complicated task, with stimuli differing on two different dimensions (tone and side). The higher number of excluded participants for this task also supports its more complicated nature. On this task, the ADHD+ANX group allocated more attention to target tones than to nontarget tones. From an accuracy standpoint, this was effective for the target tone AT and the nontarget tones ANT and UNT, with no group differences in accuracy found. However, the ADHD+ANX group made more errors on the UT, responding to the target tone when it occurred on the wrong side. This result may be reflective of an attentional bias toward tone and hypervigilance that results in impulse control challenges. As noted by Rodríguez et al. (2014), insights into why this occurs may be drawn from attentional control theory (Derakshan & Eysenck, 2009). Attentional control theory postulates that individuals with anxiety are less able to recruit top-down, goal-driven attentional processes, and instead favor bottom-up, stimuli-driven attentional processes in the presence of threat and/or negative stimuli, which results in impaired functioning (Derakshan & Eysenck, 2009; Rodríguez et al., 2014). Support for this theory in youth comes from a recent study conducted by Susa, Pitică, Benga, and Miclea (2012) that found that high-anxiety youth also self-reported low levels of attentional control and exhibited a greater attentional bias to angry faces during a visual-probe task. Although similar studies have yet to be conducted in youth with ADHD+ANX, Pliszka (1989) found that youth with ADHD+ANX displayed longer reaction times as distractor conditions became more challenging during a working memory task. It is possible that anxiety did not negatively affect attention in the present study due to the relative ease of the task and the lack of associated threat, which may have facilitated low levels of state anxiety. This may account for why youth with ADHD+ANX exhibit greater impairment than youth with ADHD or anxiety alone in a variety of real-world settings, when they are met with challenging demands such as school and the navigation of social life (Bowen et al., 2008; Jensen et al., 2001; Mikami et al., 2011). Future research incorporating varying levels of difficulty may be helpful in furthering our understanding of under what conditions anxiety may impair, rather than enhance, attention. Furthermore, the current study did not consider the individual's level of anxiety experienced during the task, therefore, measures of state anxiety may be included in future research. State anxiety may be measured through self-report ratings after task completion. However, given that youth with ADHD may not be accurate self-reporters (e.g., Hoza et al., 2004), the inclusion of psychophysiological measures such as heart rate variability or skin conductance response may also be explored as an indicator of state anxiety in this population during task completion.

One advantage of ERP methodology is the ability to examine temporal differences in neural activity associated with attentional and impulse control. An interesting pattern that emerged across the selective auditory attention task and the go/no-go task was that significant group differences appeared only on the earliest component (the EFP for the selective auditory attention task and the N2 for the go/no-go task). Consistent with research suggesting heightened hypervigilance with anxiety (Richards et al., 2014), it is possible that anxiety-related differences may be most pronounced at the earliest levels of processing. Further research exploring this hypothesis, particularly within the context of emotional or threatening stimuli, is needed to deepen our understanding of this possible temporal relation.

Although this study offers new insights into the impact of anxiety on attentional and impulse control in ADHD, it is not without limitations. The current study utilized a categorical measure of anxiety. It is possible that the impact of anxiety on attentional and impulse control may differ depending on severity of anxiety, and therefore, the addition of a continuous measure of trait levels of anxiety would be beneficial to clarify this. Furthermore, type of anxiety (e.g., test anxiety, trait anxiety/fear) has been shown to be related to different types of attentional control, with test anxiety being more related to tasks involving working memory (e.g., repeating number sequences in forward and reverse orientations) and trait anxiety being more related to Stroop performance (impulse control and flexibility; Hopko, Hunt, & Armento, 2005).

The sample was very complex diagnostically, with many youth exhibiting additional psychological diagnoses in addition to learning disabilities, ADHD, and anxiety. Although number of diagnoses did not relate to any of the ERP components of interest, it is possible that specific diagnostic profiles may be associated with neural differences. Further exploration into patterns of ERP activity with larger complex comorbid samples is needed to better understand how different patterns of comorbidity may relate to ERPs. As with number of diagnoses, a significant difference in age was observed between the two groups, which was also not associated with any of the ERP components. However, it is worth noting that this difference in age may reflect previous literature, which demonstrates that whereas challenges in youth with ADHD without anxiety may be detected earlier in development, difficulties experienced by youth with ADHD+ANX may not be evident or identified until later in development (Schatz & Rostain, 2006). As such, longitudinal studies that explore differences in attentional control within these two groups over time may be warranted.

In terms of design, the present study compared ADHD+ANX with an ADHD without anxiety control group. The addition of a typically developing control group, as well as a group with anxiety only, would help to determine how patterns of attentional and impulse control differ in youth with ADHD+ANX and whether the attentional and impulse control enhancement seen leads to similar levels of attentional and impulse control as typically developing youth. This, in combination with varying the complexity of tasks discussed above, would improve our understanding of the impact of co-occurring anxiety on ADHD. In addition to complexity, the influence of the emotional valence of tasks could also be examined. The current study focused on executive functioning processes in cold contexts, which were more cognitive in nature and did not include an affective component (Zelazo, 2015). Although enhanced attentional and impulse control were noted in the comorbid ADHD+ANX group, it is possible that relations may differ in hot contexts, which involve affectively laden tasks, as suggested by the aforementioned research by Susa et al. (2012) and Pliszka (1989). Furthermore, a recent meta-analysis by Graziano and Garcia (2016) found that youth with ADHD demonstrate greater difficulties with emotional regulation, encoding and processing emotional information, and greater emotional reactivity than typically developing youth. It is possible that youth with ADHD+ANX may have increased challenges in these domains than youth with ADHD without anxiety (Steinberg & Drabick, 2015), and future ERP research that incorporates affectively laden tasks may help to clarify this.

Another potential limitation is that all youth in the study's sample had a learning disability. As noted above, although the large majority of youth with ADHD also have learning disabilities (Mayes et al., 2000), patterns found in the present study may differ in youth with ADHD without learning challenges. Specifically, youth with both learning difficulties and mental health challenges may have greater difficulties with both executive functioning and emotion regulation than youth without these comorbid challenges (Milligan, Badali, & Spiroiu, 2015; Milligan, Phillips, & Morgan, 2015), which may be an interesting area for future investigation. Finally, the grand-averaged waveforms for the present study (see Figures 1 and 2) suggest that within- and between-group differences may be present in other components, particularly the P2. Although the P2 is not as clearly associated with attention as the other components analyzed in this study, examination of the P2 within ADHD and ADHD+ANX samples may be an area for future research. It is also interesting to note that visual inspection of the grand average overlay of the selective auditory attention task suggests that the amplitude of the P1, which follows the EFP, appears larger in the ADHD group. While the P1 was not an ERP component that was specifically addressed in this study, it invites the hypothesis that the allocation of attentional resources may be delayed in the ADHD group but when attentional resources are allocated they may in fact be stronger than the ADHD+ANX group. Future research is needed to replicate and further explore this hypothesis.

In conclusion, this is the first known study to analyze ERP indices of attentional and impulse control processes in youth with ADHD to better our understanding of the role of comorbid anxiety. The present study's ERP findings provide insight into the underlying neural processes that differentiate youth with ADHD without anxiety from youth with ADHD+ANX, suggesting that comorbid anxiety leads to increased attention allocations when sustained attention and impulse control are required. However, increased allocation of attention appears to be narrow and in the context of complex tasks that require multifocus, which may lead to poorer levels of accuracy. Furthermore, the results suggest that the impact of anxiety may be most pronounced at the earliest stages of neural processing. This is notable as differences in early ERP components reflect how soon in the trajectory of processing information individuals are able to disengage from distracting stimuli, which ultimately affects later stages of processing, and subsequent behavioral manifestations. From a treatment perspective, these results suggest that intervention may be most beneficial for youth with ADHD+ANX when it can be tailored to addressing the earliest stages of processing in the context of task complexity.

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