THE EFFECT OF COMORBID ANXIETY IN YOUTH WITH ADHD:

AN ERP ANALYSIS OF ATTENTIONAL CONTROL AND IMPULSE CONTROL

by

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The Effect of Comorbid Anxiety in Youth with ADHD:

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Masters of Arts, 2016

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Abstract

Differences in attentional and impulse control may underlie the increased impairment associated with youth with ADHD and comorbid anxiety (ADHD+ANX) compared to youth with ADHD without anxiety; however, findings from studies using behavioural and self-report measures have been mixed. This study addressed this issue by exploring the impact of the addition of anxiety on attentional and impulse control at a neural level, using event-related potentials (ERPs). Youth aged 11 to 17 with ADHD without anxiety (n = 34) and ADHD+ANX (n = 33) completed a Go/No-Go and Selective Auditory Attention task. Results indicated that the addition of anxiety in youth with ADHD was associated with enhanced early attentional processing, as well as stronger activation of impulse control, as exhibited by greater EFP and N2 amplitudes, respectively. Future directions and clinical implications of these results are discussed.

Keywords: attention-deficit/hyperactivity disorder, anxiety, attentional control, impulse control, event-related potentials

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Table of Contents

List of Tables

List of Figures

List of Appendices

Statement of the Problem

Attention Deficit/Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder characterized by levels of inattention and/or hyperactivity-impulsivity that are inappropriate for an individual's developmental level or interfere with functioning (Barkley, 2006). It is currently recognized as an important mental health concern and the most common neurodevelopmental disorder, affecting approximately 3.5% of youth worldwide (Polanczyk, Salum, Sugaya, Caye, & Rohde, 2015).

Youth with ADHD are nearly five times more likely to experience an anxiety disorder than youth without ADHD (Spencer, Biederman, & Wilens, 1999), and it is estimated that up to 50% of youth with ADHD experience comorbid anxiety (ADHD+ANX; Larson, Russ, Kahn, & Halfon, 2011). Research to date demonstrates that youth with ADHD+ANX exhibit greater impairment than youth with ADHD or anxiety alone in a variety of social, academic, and cognitive domains (Bowen, Chavira, Bailey, Stein, & Stein, 2008; Jensen et al., 2001; Mikami, Ransone, & Calhoun, 2011; Pliszka, 1989; Pliszka, 1992). Differences in attentional control and impulse control, executive functions involving the prefrontal and frontal cortical areas of the brain (Elliott, 2003; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000), have been suspected to contribute to these greater impairments (Manassis, Tannock, & Barbosa, 2000; Mayes & Calhoun, 2007; Pliszka, 1989; Pliszka 1992; Sørensen, Plessen, Nicholas, & Lundervold, 2011; Vloet, Konrad, Herpertz-Dahlmann, Polier, & Günther, 2010; Wåhlstedt, 2009). However, it remains unclear if the presence of comorbid anxiety in the context of ADHD magnifies or diminishes attentional and impulse control (Manassis et al., 2000; Newcorn et al., 2001; Pliszka, 1989; Schatz & Rostain, 2006; Vloet et al., 2010).

Event-related potentials (ERPs) are manifestations of neural activity that can be used to measure attentional and impulse control processes at the level of the brain (e.g., Dimoska, Johnstone, Barry, & Clarke, 2003; Groom et al. 2010; Johnstone, Barry, & Anderson, 2001; Lackner, Santesso, Dywan, Wade, & Segalowitz, 2013; Satterfield, Schell, & Nicholas, 1994; Stevens, Lauinger, & Neville, 2009; van der Stelt, van der Molen, Gunning, & Kok, 2001). They are collected by recording electroencephalographic (EEG) activity from electrodes placed on the scalp while simultaneously presenting a subject with a series of stimuli and/or tasks, and are computed by averaging the amplitude and latency of the waveforms generated from EEG activity over many trials (Luck, 2014). ERPs are less influenced by the response strategy of the individual compared to self-report or behavioural measures (McCarthy & Donchin, 1981). Furthermore, ERPs may allow insight into underlying neural processes that differentiate various groups, even when measures of behaviour are unable to detect group differences (Insel et. al., 2010; Harms, Martin, & Wallace, 2010). As such, given the discrepant results in the research exploring attentional and impulse control in youth with ADHD+ANX, ERPs may be a useful method for gaining a deeper understanding of the neural mechanisms that differentiate these two groups.

Using ERPs recorded during computerized tasks (i.e., Go/No-Go task, Selective Auditory Attention task), this study explored attentional control and impulse control in youth with ADHD+ANX compared to those with ADHD without anxiety. As the first known study addressing the impact of anxiety on attentional and impulse control in youth with ADHD using ERP methodology, this study will allow for examination of differences at the neural processing level. This is an important methodological advancement as it will enable us to detect group differences at the earlier stages of neural processing, independent of behavioural response. This understanding may help to address mixed findings in the literature and, in turn, inform etiology, maintenance, prevention, and targets for intervention in these highly comorbid conditions.

Introduction

Attention Deficit/Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder characterized by levels of inattention and/or hyperactivity-impulsivity that are inappropriate for an individual's developmental level or interfere with functioning (Barkley, 2006). It is currently recognized as an important mental health concern and the most common neurodevelopmental disorder, affecting approximately 3.5% of youth worldwide (Polanczyk et al., 2015). The *Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition* (DSM-5; APA, 2013) provides a behavioural phenotype of ADHD. There are two broad symptom areas: inattention and hyperactivity/impulsivity. In order for youth age 16 or younger to meet threshold for a diagnosis of ADHD, they must present with at least six symptoms that are predominantly inattentive, and/or at least six symptoms that are predominantly hyperactive and impulsive within the last 6 months, and several inattentive or hyperactive-impulsive symptoms must be present before age 12 (APA, 2013). Furthermore, several symptoms must be present in two or more settings, such as home or academic settings, and these symptoms must interfere with optimal functioning in these settings (APA, 2013).

Youth with inattentive symptoms of ADHD may appear easily distracted and have difficulty staying focused. They may make careless mistakes and/or fail to complete their school work or other important tasks. They may also have trouble maintaining focus in class or during conversations with parents and peers. Challenges with organization, time management, and meeting deadlines may also be associated with inattention. Youth with inattentive symptoms of ADHD may exhibit forgetfulness in a variety of activities, including doing chores or homework, returning phone calls, and keeping deadlines or appointments (APA, 2013).

Hyperactivity is defined broadly as excessive motor activity or talkativeness when it is inappropriate (APA, 2013). Youth with hyperactive symptoms may demonstrate excessive fidgeting, tapping of hands and/or feet, squirming excessively when seated, or leaving their seat when remaining seated is expected. Excessive running and climbing may also be demonstrated, leading people to often describe youth as being restless, challenging to keep up with, and acting as if they were “driven by a motor” (APA, 2013, p. 60). Impulsivity, on the other hand, refers to abrupt, potentially reckless, actions that occur without premeditation. This may include verbal behaviours such as shouting an answer in a classroom setting or elsewhere before the question is completed, completing other people’s sentences, and/or interrupting others during conversation. Behaviourally, impulsivity may be reflected in challenges with waiting, such as waiting in a line-up or for one’s turn in a game, or doing or taking things without asking or being given permission (APA, 2013). Youth can present with challenges in one or both of these symptom areas, represented by three subtype classifications: predominantly inattentive presentation, predominantly hyperactive/impulsive presentation, and combined presentation. The majority of youth with ADHD exhibit the combined presentation (APA, 2013).

Given the above description of symptomatology, it is perhaps not surprising that youth with ADHD experience challenges in a broad range of domains, including emotion regulation (Braaten, & Rosén, 2000; Steinberg & Drabick, 2015), social skills (Murray-Close et al., 2010; Normand, Schneider, & Robaey, 2007) and academic performance (Daley & Birchwood, 2010; Loe & Feldman, 2007). In addition, comorbidity, which reflects the presence of multiple diagnoses within one individual, is highly prevalent in ADHD (Halldorsdottir & Ollendick, 2014). Behaviour disorders are most common, with oppositional defiant disorder occurring in approximately 50% of youth with combined inattentive/hyperactive presentations and approximately 25% of youth with predominantly inattentive presentations, and conduct disorder occurring in approximately 25% of youth with combined presentations of ADHD (APA, 2013). Compared to youth in the general population, youth with ADHD are nearly five times more likely to experience an anxiety disorder than youth without ADHD (ADHD+ANX; Spencer et al., 1999). Exact rates, however, have varied from 27% (Spencer et al., 1999) to 40% (Tannock, 2009).

Fear and anxiety surrounding, for example, separation from parents, interacting with strangers, being alone, negative evaluation, and thoughts about the future, are common and expected across development (Weems & Costa, 2005). However, anxiety disorders are different from developmentally normative fear and anxiety in that they are excessive (i.e., significantly interfere with functioning) and/or persist well beyond developmentally appropriate stages (Weems & Costa, 2005). Anxiety disorders occur in approximately 6% of youth, making it the most common psychological disorder in childhood (Cartwright-Hatton, McNicol, & Doubleday, 2006). The anxiety disorders outlined in the DSM-5 (2013) include separation anxiety disorder (i.e., fear and anxiety surrounding separation from attachment figures), selective mutism (i.e., failure to speak in social situations when expected), specific phobias (i.e., fear and anxiety surrounding specific objects or situations), social anxiety disorder (i.e., fear and anxiety surrounding social interactions in which the individual may be evaluated), panic disorder (i.e., recurrent and unexpected surges of intense fear), agoraphobia (i.e., fear and anxiety surrounding situations in which escape may be difficult), and generalized anxiety disorder (i.e., persistent and excessive anxiety regarding multiple domains). Many of these anxiety disorders persist beyond childhood if left untreated (APA, 2013).

It is important to note that it can be difficult at times to recognize anxiety in youth with ADHD. Symptoms of anxiety in youth, such as attention seeking, behavioural avoidance, overdependence, temper tantrums, and compliance refusal, may be misinterpreted because of overlap with ADHD symptoms (Fraire & Ollendick, 2013). Furthermore, anxiety disorders are often not suspected in hyperactive youth, and reciprocally ADHD is often not suspected in inhibited children (Spencer, Biederman, & Mick, 2007).

Research to date demonstrates that youth with comorbid ADHD+ANX exhibit greater impairment than youth with ADHD or anxiety alone in a variety of academic, cognitive, and social domains (Bowen et al., 2008; Jensen et al., 2001; Mikami et al., 2011; Pliszka, 1989; Pliszka, 1992). For example, Jensen et al. (2001) found that children aged 7 to 10 with comorbid ADHD+ANX performed worse academically and had a higher prevalence of learning disabilities compared to youth with ADHD without anxiety (but with comorbid externalizing disorders). In regards to social impairment, Bowen et al. (2008) found that youth aged 8 to 17 with ADHD+ANX had lower levels of self- and parent-reported social competence than did youth with ADHD only or anxiety only. Consistent with this, Mikami et al. (2011) found that anxiety in boys aged 6 to 10 with ADHD was associated with poorer social functioning on parent and teacher report measures. Differences in attentional control and impulse control have been suspected to contribute to these greater impairments (Manassis et al., 2000; Mayes & Calhoun, 2007; Pliszka, 1989; Pliszka 1992; Sørensen et al., 2011; Vloet et al., 2010; Wåhlstedt, 2009).

Attentional and Impulse Control in Youth with ADHD

Symptoms of ADHD and its associated impairments are posited to arise primarily from deficits in executive functioning (Barkley, 1997; Barkley, 2006; Castellanos & Tannock 2002; Pennington & Ozonoff, 1996; Schachar, Mota, Logan, Tannock, & Klim, 2000; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Executive functions are metacognitive skills involving the prefrontal and frontal cortical areas of the brain that allow for the execution, regulation, and planning of behaviour (Elliott, 2003; Miyake et al., 2000). A meta-analysis examining 83 studies measuring executive functions in children and adolescents with ADHD found that youth with ADHD exhibit significant impairment in all executive functioning tasks, with the largest effects found in tasks that require attentional control and impulse control (i.e., continuous performance and stop-signal tasks; Willcutt et al., 2005).

There are differing theories on how attentional control, which can be defined as the ability to effectively orient and sustain attention while filtering out irrelevant stimuli (Muris, Mayer, van Lint, & Hofman, 2008), is related to executive functioning. For example, Stuss (1992) views attentional control as a core executive function which develops alongside other executive functions as the prefrontal cortex matures, while MacCoon and colleagues (2004) view attentional control as a precursor to other executive functions, which are only able to develop once attention can be effectively directed and managed. Conversely, Ruff and Rothbart (1996) view executive functions as a precursor to attentional control, theorizing that it is only once children begin to self-regulate that attentional control begins to develop. Despite the differences in these theories, all view attentional control as an essential aspect of effective executive functioning. Further support for this view comes from research demonstrating that one of the defining features of youth with ADHD, a group known to experience deficits in executive functioning (Barkley, 1997), are impairments in attentional control (APA, 2013; Mayes & Calhoun, 2007). For example, Mayes and Calhoun (2007) found that when compared to age-matched controls without ADHD, children and adolescents aged 6 to 16 with ADHD performed significantly worse on the Gordon Diagnostic System (GDS; Gordon, DiNiro, Mettelman, &

Tallmadge, 1989), a computerized visual continuous performance task that measures both sustained attention and sustained attention during distraction. These same children and adolescents also performed significantly worse on the Wechsler Digit Span subtests, an auditory measure of working memory that requires attentional control (Mayes & Calhoun, 2007; Wechsler, 1991; Wechsler, 2003).

Deficits in impulse control, reflecting challenges in the ability to actively suppress, interrupt, or delay an action (Clark, 1996), have a particularly profound impact on functioning. This is because impulse control allows the execution of appropriate responses by providing the cognitive system with the necessary delay to process information so that a more controlled response can take place (Johnstone et al., 2007; Logan, 1994). Challenges have been seen across tasks measuring impulse control in youth with ADHD. For example, youth with ADHD performed significantly worse than normative samples during a computerized go/no-go task, which required them to press a key when a frequent stimulus appeared on the screen (i.e., the go condition), but to withhold their response when an infrequent figure appeared (i.e., the no-go condition; Wåhlstedt, 2009). In addition to deficits in attentional control, Mayes and Calhoun (2007) found that when compared to age-matched controls without ADHD, children and adolescents aged 6 to 16 with ADHD made significantly more errors of commission (reflecting decreased impulse control) in the delayed response subtest of the GDS (Gordon et al., 1989). In another study, Wåhlstedt (2009) found that children aged 5 to 7 with ADHD committed significantly more errors of commission compared to normative samples in both the go/no-go and Stroop task. Similarly, also using a Stroop task, Berlin and Bohlin (2002) found that youth with ADHD were significantly worse at saying an opposite response when presented with an image on a computer screen (e.g., say “boy” when presented with an image of a girl; Wåhlstedt, 2009). Taken together, these findings indicate that youth with ADHD commit errors of commission at a markedly higher rate than youth without ADHD, which is reflective of difficulty with impulse control.

Attentional and Impulse Control in Youth with ADHD+ANX

While challenges with attentional and impulse control in youth with ADHD are well documented (Mayes & Calhoun, 2007; Wåhlstedt, 2009; Willcutt et al., 2005), a clear picture of the impact of comorbid ADHD+ANX on attentional and impulse control has yet to be developed. Specifically, it remains unclear if the presence of comorbid anxiety in the context of ADHD magnifies or diminishes attentional and impulse control (Manassis et al., 2000; Newcorn et al., 2001; Pliszka, 1989; Schatz & Rostain, 2006; Vloet et al., 2010). Some researchers have found that anxiety magnifies challenges with attention. Pliszka (1989) found that, although youth aged 6 to 12 with ADHD+ANX were less likely to display off-task and hyperactive behaviour than youth with ADHD according to teacher and parent ratings, they displayed longer reaction times on a task in which they had to use working memory, each task with various distracting conditions (i.e., no-, low-, and high-distractor conditions). As distractor conditions became more challenging, youth with ADHD+ANX were slower to respond than ADHD only. Pliszka (1989) concluded that youth with ADHD+ANX have difficulties not only with processing speed, but also with working memory and filtering out to-be ignored stimuli, suggestive of problems with attentional processes.

In contrast, other research has found that the addition of anxiety in youth with ADHD may ameliorate deficits in attentional control (Sørensen et al., 2011; Vloet et al., 2010). Using a visual set-shifting task as a measure of attentional control, Vloet and colleagues (2010) found that youth with ADHD had a high number of errors, while the performance of youth with

ADHD+ANX was comparable to that of controls without ADHD or anxiety. Furthermore, using an inattention subscale consisting of nine items used to define the inattention subtype of the ADHD diagnosis in the *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition* (DSM-IV; APA, 1994), Sørensen and colleagues (2011) found that comorbid anxiety in youth with ADHD was associated with better attentional control. Finally, others have reported no additional impact of anxiety on attention in ADHD. For example, Newcorn et al. (2001) did not find significant differences in omission errors or reaction times during a continuous performance task in children aged 7 to 9 with ADHD+ANX compared to children with ADHD only, indicting similar levels of attention between groups.

Similar confusion exits with regard to impulse control. Some studies have found that the addition of anxiety in youth with ADHD results in improved impulse control across multiple measures (Manassis et al., 2000; Pliszka, 1989; Pliszka, 1992). For example, using a shape-paradigm stop-signal task, youth aged 6 to 12 with ADHD+ANX made fewer errors of commission than youth with ADHD alone, indicating better impulse control (Pliszka, 1989; Pliszka, 1992). Manassis et al. (2000) found similar results using two concurrent tasks: a go/no-go task which required youth to discriminate between X's and 0's, and a stop-signal task. Enhanced inhibition in ADHD+ANX has also been noted on the Inhibit scale of the Behaviour Rating Scale of Executive Function parent-report measure (BRIEF; Gioia, Isquith, Retzlaff, & Espy, 2002). Sørensen and colleagues (2011) found that comorbid anxiety in children aged 7 to 9 with ADHD was associated with better impulse control compared to aged-matched children with ADHD only.

Other studies have failed to show this inhibition-enhancement effect. Using a stop-signal task, which required youth to inhibit a prepotent response upon the presentation of a tone, Korenblum, Chen, Manassis, and Schachar (2007) did not find any differences in impulse control in youth aged 6 to 14 with ADHD without anxiety compared to youth with ADHD+ANX. Similarly, using number of commission errors during a go/no-go task, Vloet and colleagues (2010) found that the addition of anxiety in youth aged 8 to 15 with ADHD had no effect on impulse control. Likewise, using a continuous performance task in which youth had to to press a button when X was preceded by A, and a different button to their left for all other stimuli, Newcorn et al. (2001) did not find significant differences in impulsivity for children aged 7 to 9 with ADHD+ANX compared to youth with ADHD only, or ADHD and other comorbid diagnoses, when impulsivity was defined by two types of commission errors; those in which A was not followed by X with short response times, and A-only errors with long response times. Taken together, these mixed results suggest that there is a need for a new approach to examining the impact of anxiety to ADHD on attentional and impulse control.

Using Event-Related Potentials as a Measure of Attentional and Impulse Control

Measuring attentional and impulse control in youth with ADHD+ANX and ADHD without anxiety at a neurocortical level may shed light on these discrepant findings. Event-related potentials (ERPs) provide a picture of what is happening at the level of the brain. ERPs are collected by recording electroencephalographic (EEG) activity from electrodes placed on the scalp while simultaneously presenting a subject with a series of stimuli and/or tasks. ERPs are computed by averaging the amplitude and latency of the waveforms generated from EEG activity over many trials on a given task (Luck, 2014). While amplitudes reflect the amount of cortical resources generated following a stimulus, latencies reflect the timing of these resources (Luck, 2014). ERPs are less influenced by the response strategy of the individual compared to self-report or behavioural measures (McCarthy & Donchin, 1981). Furthermore, ERPs may allow insight into underlying neural processes that differentiate among groups, even when measures of behaviour are unable to detect group differences (Insel et. al., 2010; Harms et al., 2010). Given the discrepant results in the research exploring youth with ADHD+ANX compared to youth with ADHD without anxiety, ERPs may be a useful method for gaining a deeper understanding of the neural mechanisms that differentiate these two groups.

ERP Components Reflective of Attentional Control

The Early Frontal Positivity (EFP), N1, and P3 components are thought to reflect aspects of attentional control (Lackner et al., 2013; Stevens et al., 2009).

EFP. The EFP is observed approximately 50 to 150 ms post auditory stimulus to attended auditory stimuli and is most prevalent over midline fronto-central sites (e.g., Fz, FCz, and Cz; Coch, Sanders, & Neville, 2005; Lackner et al., 2013; Sanders, Stevens, Coch, & Neville, 2006; Stevens et al., 2009). This pronounced broad amplitude of early positivity to attended (i.e., target) auditory stimuli has been reported in children as young as 3 and as old as 14 years of age (Coch et al., 2005; Lackner et al., 2013; Sanders et al., 2006; Stevens et al., 2009), but appears not to be observed in adults (Coch et al., 2005; Sanders et al., 2006). Although it is not yet clear why this component does not appear in adults, it is likely related to brain maturation and frontalization of neurological activity with age (Lackner et al., 2013).

Stevens and colleagues (2009) examined attentional processes in children aged 2 to 8 using a dichotic listening task in which participants had to pay attention to a story played in one ear with target tones dispersed throughout, while a different story was simultaneously presented in other ear, also with tones dispersed throughout (non-target tones). They found that typically developing children elicit a larger EFP amplitude 100 to 200 ms post stimulus to target versus non-target tones. Jonkman and colleagues (1997) found that the EFP was elicited in the context of a selective auditory attention task, which required youth to press a button when they heard a target tone in the attended ear and to inhibit pressing a button for all non-target tones. In this study they found that peak EFP amplitudes were significantly smaller for attended target tones in youth aged 7 to 13 with ADHD compared to age-matched controls without ADHD. The same researchers also found that while controls without ADHD demonstrated larger EFP amplitudes to attended visual stimuli than unattended visual stimuli, youth with ADHD failed to show such an effect (Jonkman, Kenemans, Kemner, Verbaten, & van Engeland, 2004). Also using a selective auditory attention task, Lackner and colleagues (2013) found that youth aged 12 to 14 who were rated by their parents as having high levels of challenge with working memory (an area of executive function highly dependent on attentional control; Blair & Ursache, 2011) demonstrated larger EFP amplitudes to target tones in the unattended ear, although EFP amplitudes to target tones in the attended ear did not vary as a function of group (Lackner et al., 2013). There were no significant differences for EFP latencies. However, there was a trend towards shorter EFP latencies to target tones in the unattended ear in youth who were rated as having fewer challenges with working memory (Lackner et al., 2013). This suggests that attention in these youth was directed to target tones in the unattended ear for a shorter period of time, which reflects better attentional allocation and shifting (Lackner et al., 2013). Taken together, these results suggest that the EFP is associated with attentional control, with larger amplitudes for target tones and smaller amplitudes for non-target tones indicating better attentional control (Lackner et al., 2013). No known studies to date have examined the EFP in anxiety or ADHD+ANX samples.

N1. The ERP component typically associated with auditory attentional control is the N1, which is observed approximately 100 ms after a subject is presented with an auditory stimulus and is most prevalent over midline fronto-central sites (e.g., Fz, FCz, and Cz; Luck, 2014). The difference between N1 amplitudes for target versus non-target stimuli is called the N1d effect, and is characterized by larger N1 amplitudes to target stimuli (Hillyard, Hink, Schwent, & Picton, 1973; Woods, 1990).

Research demonstrates that youth with ADHD exhibit smaller N1 amplitudes and shorter N1 latencies than youth without ADHD (Johnstone et al., 2001; Satterfield et al., 1994). For example, using an audio-oddball task, Johnstone and colleagues (2001) found that youth aged 8 to 17 with ADHD exhibited smaller N1 amplitudes to target tones compared to age-matched controls without ADHD, even when ADHD subtype was controlled for. In a different study that used a selective attention task, which required youth to ignore visual stimuli and also to press a button to target tones and withhold their response to non target tones, 6-year-old children with ADHD exhibited significantly smaller N1 amplitudes and shorter N1 latencies to target tones compared to typically developing children without ADHD (Satterfield et al., 1994). These findings are consistent with literature demonstrating that youth with ADHD have significant challenges with attentional control, and more specifically, difficulty with increasing attentional allocation to target stimuli (Mayes & Calhoun, 2007).

In regards to anxiety, Hogan, Butterfield, Phillips, and Hadwin (2007) found that during a novelty audio-oddball task in which unexpected noises were presented within an audio-oddball paradigm, youth aged 10 to 14 with self-reported ratings of high anxiety demonstrated significantly larger N1 amplitudes and longer N1 latencies to novel tones compared to youth with low anxiety. The same study also found a trend of larger peak N1 amplitudes for deviant targets in youth with high anxiety (Hogan et al., 2007). No known studies to date have examined the N1 as a measure of attentional control in ADHD+ANX samples.

P3b. The P3b (also referred to as the P300) is another component reflective of attentional control and is most prevalent over midline fronto-central sites (e.g., Fz, FCz, and Cz; Luck, 2014). This component is produced in the context of having to attend to and classify visual or auditory stimuli (Luck, 2014). This is not to be confused with the P3a or novelty P3, which is elicited by classification of highly deviant, task-irrelevant auditory and visual stimuli (Luck, 2014).

Research demonstrates that youth with ADHD exhibit smaller P3b amplitudes compared to controls without ADHD, indicating less attentional resource allocation to target stimuli (Janssen, Geladé, van Mourik, Maras, & Oosterlaan, 2016; Kratz et al., 2011; Satterfield et al., 1994). Kratz and colleagues (2011) found this pattern using a computerized visual attentional network task, a modification of the fish flanker task, in which youth were instructed to focus on a cross in the middle of the computer screen, and also to feed a fish that would appear above or below the cross by pressing the button that matched the direction in which the fish was pointing. There were three cue conditions; the no-cue condition, in which the fish were presented without a cue, the neutral-cue condition, in which an asterisk at the centre of the screen indicated that the target fish was about to appear; and the spatial-cue condition, in which an asterisk was presented at the location of the target fish, indicating not only that the target fish was about to appear but also its location on the screen (Kratz et al., 2011). This target fish was surrounded by two identical fish on either side, which either pointed in the same direction (congruent trials) or in the opposite direction (incongruent trials; Kratz et al., 2011). Using this task, Kratz and colleagues (2011) found smaller P3b amplitudes in youth aged 8 to 11 with ADHD, compared to age-matched controls without ADHD, for both cues and targets. This finding suggests that youth with

ADHD allocate less attentional resources for both cue processing and attended targets, which is indicative of poor attentional control (Kratz et al., 2011).

Similar findings are also documented in studies which employ auditory stimuli. For example, Satterfield and colleagues (1994) found that, compared to age-matched controls, school-aged children with ADHD exhibit smaller P3b amplitudes to target tones during an audio-oddball task. Janssen and colleagues (2016) recently replicated these results, finding that P3b amplitudes were significantly smaller for targets-tones in youth aged 7 to 13 with ADHD compared to typically developing age-matched controls.

Similar results have been found on selective visual attention tasks. For example, van der Stelt and colleagues (2001) also found that children with ADHD exhibit decreased P3b amplitudes to attended versus unattended stimuli when compared to age-matched controls. In this task, children aged 2 to 12 were presented with two types of circles; half with gaps, which served as the unattended targets, and half without gaps, which served as attended targets. Circles varied in colour (blue or red), with rare-occurring non-gap circles being the attended-target.

P3b activity in youth with anxiety has seldom been explored. The limited research that is available suggests that anxiety may be associated with increased P3b amplitudes. For example, Daruna, Rau, & Strecker (1991) found that compared to age-matched controls, children aged 3 to 7 who are rated as high in anxiety by their parents had larger P3b amplitudes to target tones during an audio-oddball task. No known studies to date have examined the P3b as a measure of attentional control in ADHD+ANX samples.

ERP Components Reflective of Impulse Control

The N2 and P3 are ERP components consistently associated with inhibition (Lewis, Lamm, Segalowitz, Stieben, & Zelazo, 2006; Luck, 2014).

N2. The N2 is observed approximately 200 to 400 ms after a subject is presented with a stimulus that indicates that they must inhibit their response, and they successfully do so (Falkenstein, Hoormann, & Hohnsbein, 1999; Eimer, 1993; Jodo & Kayama, 1992). The N2 is most prevalent at medial-frontal sites (e.g., Fz, FCz, and Cz; Luck, 2014) and is often referred to as the ‘‘inhibitory’’ or “no-go” N2 (Lewis et al., 2006). N2 amplitudes for tasks requiring impulse control are significantly smaller in youth with ADHD relative to youth without ADHD (Albrecht, Banaschewski, Brandeis, Heinrich, & Rothenberger, 2005; Dimoska et al., 2003; Liotti, Pliszka, Higgins, Perez, & Semrud-Clikman, 2010; Smith, Johnstone, & Barry, 2004). For example, using a computerized stop-signal task in which participants were required to press one of two buttons (T or O) according to which letter was presented, but withhold their response when a target tone occurred, youth aged 7 to 12 with ADHD had smaller N2 amplitudes for correct inhibitions compared to age-matched controls without ADHD, which is suggestive of weaker activation of impulse control (Dimoska et al., 2003). Consistent with this finding, Liotti and colleagues (2005; 2010) found that N2 amplitudes were significantly smaller in youth aged 9 to 15 with ADHD compared to age-matched controls without ADHD during correct inhibitions on a similar stop-signal task. Furthermore, while the difference between N2 amplitudes was typically greater for trials with correct inhibition versus failed inhibition, this pattern differed in youth with ADHD (Liotti et al., 2010). For example, Liotti and colleagues (2010) found that youth with ADHD failed to show a correct-related increase in N2 amplitudes, while a significant increase in N2 amplitudes for correct inhibitions versus failed inhibitions was observed in controls. Using a go/no-go task, Johnstone, Barry, Markovska, Dimoska, & Clarke (2009) found that youth aged 8 to 14 with ADHD exhibited significantly reduced N2 amplitudes to no-go stimuli compared to age-matched controls. Groom et al. (2008) also found a reduction in no-go N2 amplitudes in adolescents with ADHD compared to typically developing adolescents.

An opposite pattern of results has been found in youth with anxiety (Hum, Manassis, & Lewis, 2013a). For example, using a computerized go/no-go task in which youth were instructed to press a button for all facial expressions presented but to avoid pressing the button when the face was a particular gender, Hum et al. (2013a) found that youth aged 8 to 12 with anxiety had significantly larger no-go N2 amplitudes than youth without anxiety. They also found that youth with anxiety exhibited similar N2 amplitudes regardless of trial type, while control youth exhibited greater amplitudes during the no-go condition, compared to the go condition (Hum et al., 2013a). In a follow-up study conducted by Hum and colleagues (2013b), they found that youth who experienced a decrease in anxiety symptoms following treatment demonstrated a significant increase in no-go N2 amplitudes. Similarly, Lamm et al. (2014) found greater no-go N2 amplitudes were associated with greater behavioural inhibition and greater social reticence, but not greater levels of anxiety as measured by the Child Behavior Checklist in children aged 7 (CBCL; Achenbach & Rescorla, 2001).

Contrary to the above findings, Lewis et al. (2008) found that no-go N2 amplitudes in aggressive youth aged 8 to 12 presenting with anxiety did not differ pre- or post-treatment when compared to controls. No known studies to date have examined the N2 as a measure of impulse control in ADHD+ANX samples.

P3. The P3 is observed approximately 300 to 500 ms post-stimulus and is also most prevalent at medial-frontal sites (Luck, 2014). As noted above, the P3 component is reflective of attentional control, particularly within the context of stimuli categorization. However, unlike its generation in tasks measuring selective audio/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 (Liotti et al., 2005; Pliszka et al., 2007). Given this context and similarity to the N2, it is often reported on trials involving correct inhibition (Lewis et al., 2006).

Using a computerized stop-signal task in which participants were required to press one of two buttons (A or B) according to which letter was presented, but withhold their response when the letter S appeared, Liotti and colleagues (2005), found that boys aged 9 to 11 with ADHD demonstrated smaller P3 amplitudes for correct “stop” trials compared to age-matched controls without ADHD. Liotti and colleagues (2010) also found that youth aged 9 to 15 with ADHD demonstrated smaller P3 amplitudes for incorrect “stop” trials compared to age-matched controls without ADHD. Similarly, using a go/no-go task, Groom et al. (2010) found reduced P3 amplitudes to both go and no-go stimuli in youth aged 9 to 15 with ADHD compared to age-matched controls. This is also consistent with findings from Rodriguez and Baylis (2007), who found that young adults aged 18 to 24 with self-reported symptoms of ADHD consistently exhibited smaller P3 amplitudes to go and no-go stimuli than aged-matched controls who report low on ADHD symptoms.

Although studied far less, anxiety has been associated with the opposite effect, with larger P3 amplitudes generated during go/no-go tasks (Sehlmeyer et al., 2010). For example, Sehlmeyer and colleagues (2010) found that self-reported anxiety sensitivity in undergraduate students was related to larger no-go P3 amplitudes. No known studies to date have examined the P3 as a measure of impulse control in ADHD+ANX samples.

Study Objectives

Given that a clear picture of the impact of anxiety on ADHD does not currently exist, the objective of this study was to explore this issue using ERPs. Specifically, this study explored if the addition of anxiety in youth with ADHD results in increased or diminished challenges in attentional control and impulse control at a neural level using ERP methodology.

Method

Participants

This study used pre-treatment data collected as part of a larger ongoing treatment trial being conducted with an urban-based mental health program for youth with learning disabilities and mental health disorders. A sample of 67 (n = 33 ADHD+ANX, n = 34 ADHD without anxiety) English speaking youth aged 11 to 17 (M = 12.91, SD = 1.60) participated in this study. All youth in the study have a diagnosis of a learning disability, which is a common comorbid disorder seen in 40 to 80% of youth with ADHD (Tabassam & Grainger, 2002). This study utilized the definition of learning disability used by the mental health centre for treatment eligibility. Specifically, youth had to have a previous psychoeducational assessment that indicated that they had average or above levels of cognitive abilities, with significantly lower levels of academic achievement in reading, writing or math, and information processing challenges in at least one area (e.g., memory, processing speed, executive functions). Parents of youth were either provided with information about the study at an orientation evening for the treatment group or by the intake coordinator for the waitlist control group, and were then invited to contact the Child Self-Regulation Lab for more information. If they expressed interest and a willingness to be contacted, the research coordinator from the Child Self-Regulation Lab called them and provided further information about the study and invited them to participate. Participants received three community service hours, as well as an honorarium of $25 to cover expenses related to travel and parking. Ethical approval of the project was obtained from Ryerson University.

Procedure

Data collection took place at the Institute for Stress and Wellbeing at Ryerson University. Youth and their parents attended a 3-hour testing session. Following a brief introduction to the testing environment, electrode sensor nets, and recording system, parental and youth consent were obtained and questionnaires were completed. Parents then completed the Mini International Neuropsychiatric Interview (MINI-KID; Sheehan et al., 1998) to assess and confirm the presence of mental health issues, including ADHD and anxiety, using DSM-IV-TR criteria (APA, 1994). During this time, using the International 10/20 BioSemi ActiveTwo EEG (BioSemi, 2007) system, youth first had their head circumference measured in order to determine the correct electrode sensor cap size. Once the correct cap size was placed, site Cz was centered on the youth's head by measuring from the nasion to inion, and right earlobe to left earlobe. Skin electrodes EX1 and EX2 were placed on the participant's left and right mastoids, and youth were instructed to fasten their cap's chin strap. Using new plastic syringes, gel was applied to Ppz and Iz electrode sensor sites, and then all subsequent sites. The following skin electrodes were then placed; EX3 and EX4 on left and right horizontal eye, EX5 and EX6 on left and right vertical eye, and EX7 on right collarbone and EX8 on bottom left of ribcage. Once all electrodes were applied, participants were seated in an electrically shielded room, and EEG activity was recorded at the scalp sites at a sampling rate of 512 Hz with 0.1-100 Hz analog filtering. Monopolar displays and triggers were checked to ensure waves were being read from each electrode sensor. All electrode offset channels were set to 50mV and checked that they were within the -40mV to 40mV range to ensure minimal electrical interference. Youth were then instructed to complete a series of computer tasks while EEG activity was recorded.

Measures

Computerized Tasks

Selective Auditory Attention Task. The Dual Channel Audio Oddball task employed by Lackner and colleagues (2013) was used for the current study to examine attentional control. This task was presented using E-Prime software (Psychological Software Tools, 2012). Two digitized sounds were presented using two computer speakers located to the left and right side of the participant. The stimuli consisted of two 200 ms tones: a 1000Hz non-target tone presented at a rate of 88%, and a 2000Hz target tone presented at a rate of 12%. During an initial practice block, participants were presented with an example of each type of stimulus and asked to perform 10 practice trials whereby sounds were presented with a variable interstimulus interval of 600–800 ms, randomized across the left and right speakers. Participants were then instructed to attend to one side only and to ignore all sounds presented to the other side. While remaining visually fixated on a cross at the center of the computer screen, participants were asked to respond by pressing a button on a keypad with their dominant hand when they heard the target tone in the attended side, and not to respond otherwise. Task instructions were initially presented by the research assistant and in written form on the computer monitor, while subsequent blocks of trials were presented both in written form and concurrently read aloud by a pre-recorded female voice. The test trials include four blocks of 200 trials each. Trial breakdown across the entire task was as follows: 48 trials of 2000 Hz tones presented to the attended ear (attended targets; ATs), 48 trials of 2000 Hz tones presented to the unattended ear (unattended targets), 352 trials of 1000 Hz tones presented to the attended ear (attended non-targets; ANTs), and 352 trials of 1000 Hz tones presented to the unattended ear (unattended non-targets). After the completion of each 200-trial block, there was a 20 second break in which participants were asked to switch their side of attention and to respond to target tones on that side only. All participants began the task attending to their right side. The task took approximately 15 minutes to complete. For the current study, response to attended targets, specifically differential response to ATs and ANTs, was used as the primary measure of attentional control. Recording EEG throughout the task allowed the analyses of patterns indicative of attentional control, including larger EFP, N1, and P3b amplitudes for AT tones, and smaller EFP, N1, and P3b amplitudes for ANT tones. Accuracy (defined as the percentage of accurate responses to ATs), errors (defined as the percentage of inaccurate responses to ANTs), and response time to ATs were also measured to explore potential groups differences in behavioural response.

Go/No-Go Task. This task was partly adapted from a task developed by Garavan, Ross, and Stein (1999) and was presented using E-Prime software (Psychological Software Tools, 2012). Participants were required to press a button as fast as possible whenever a character from the Mr. Men Series (Hargreaves, 2010; see *Appendix I*) flashed on the computer screen (the "go" condition). Participants had to withhold a second response if the character presented itself twice in a row (the "no-go" condition). Thus, participants were instructed to press a button for each character presented, but to inhibit pressing the button when a character was repeated a second time in succession. Error feedback was provided, indicated by a red square in the middle of the screen following incorrect responses, omitted responses, and late responses. Correct responses accumulate more points and accumulated points were displayed on a thermometer on the screen after every 20 trials. Points 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). The task took approximately 20 minutes to complete. Recording EEG throughout the task allowed the analysis of patterns indicative of impulse control, including larger N2 and P3 amplitudes for correct no-go trials. In addition to this, group differences in omission errors (i.e., not pressing the button, or not responding quickly enough, to a “go” target) and commission errors (i.e., pressing the button to a “no-go” target), as well as response times, were also measured.

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, Sejnowski1, & Scott, 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 target and non-target stimuli correctly responded to.

Following this, data from each trial for both the selective auditory attention and go/no-go tasks were averaged into ERP segments of 1000 ms for target and non-target stimuli correctly responded to (i.e., 800 ms post stimulus and 200 ms pre-stimulus baseline). This created averaged overall waveforms for each trial type for each participant (i.e., correct AT and ANT trials; correct go and no-go trials). These data were then exported into ERPScore, and sites Fz, FCz, and Cz, in which peak amplitudes and latencies are maximal for the components of interest, were explored. Please see below for a sample grand-averaged ERP waveform with labeled ERP components.

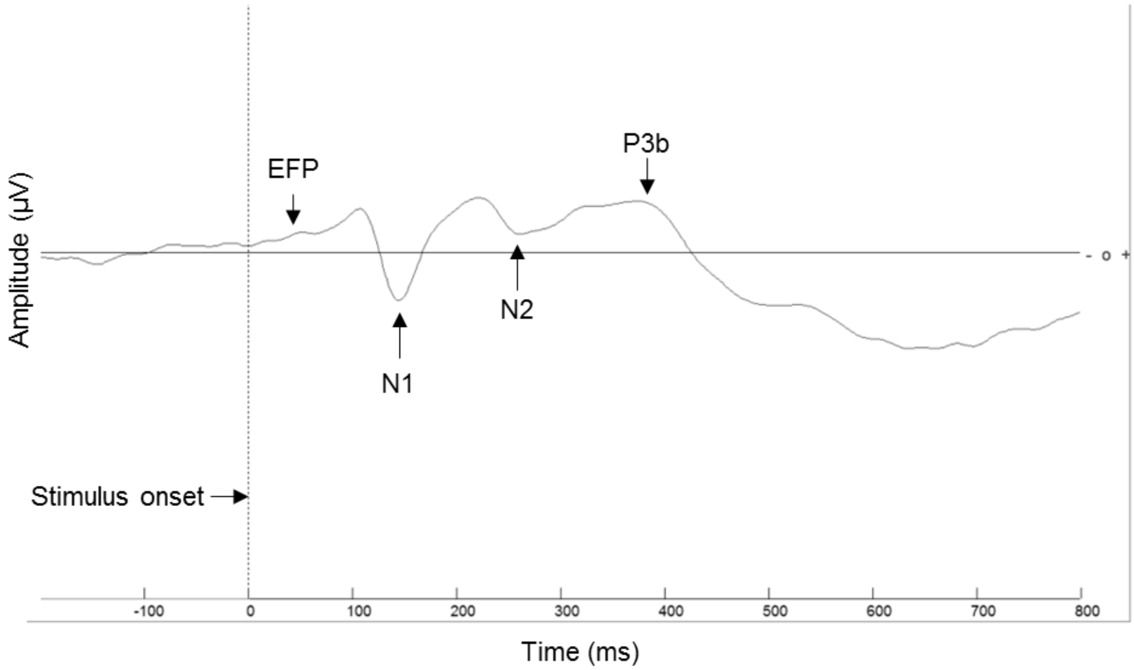

Figure 1. Sample grand-averaged ERP waveform.

ERP components were manually identified and scored using the following criteria, and carried out by a coder blind to participant characteristics (e.g., diagnostic group, demographic information):

- The EFP was scored as the most positive peak 50 to 150 ms post stimulus during the selective auditory attention task.
- The N1 was scored as the most negative peak 85 to 215 ms post stimulus during the selective auditory attention task.
- The P3b was scored as the second bump of positivity 250 to 600 ms post stimulus during the selective auditory attention task.
- The N2 was scored as the most negative peak 200 to 500 ms post stimulus during the go/no-go task.
- The P3 was scored as the most positive peak 250 to 600 ms post stimulus during the go/no-go task.

Assessment of Mental Health Disorders

Mini International Neuropsychiatric Interview for Children and Adolescents (MINI-KID; Sheehan et al., 1998). The MINI-KID is a structured diagnostic interview for children and adolescents (ages 6 to 18 years old), as well as their parents. The interview was administered by graduate students, under the supervision of a child clinical psychologist, to youth and their parents. The interview assessed the presence of 24 DSM-IV (APA, 1994) child and adolescent psychiatric disorders as well as the risk of suicide. Inter-rater and test-retest reliability correlations range from .64 to 1.00 for all individual MINI-KID disorders except dysthymia. Additionally, high concordance between the parent version (MINI-KID-P) and the standard MINI-KID has been found. The MINI-KID was used to confirm the presence of ADHD and anxiety, as well as ADHD subtype. It should be noted that the DSM-5 had not yet been released at the time when data collection had begun, and as such, DSM-IV criteria were used. The anxiety disorders included were as follows: separation anxiety disorder, specific phobia, social anxiety disorder (social phobia), panic disorder, agoraphobia, and generalized anxiety disorder (GAD). All youth who met DSM-IV criteria for ADHD+ANX or ADHD without anxiety by parent or youth report were included. Youth with additional comorbidities, with the exception of psychosis, were also included.

Other Participant Characteristics. Given that factors such as intelligence (Lahey et al., 1998), age (Casey et al., 1997; Casey, Giedd, & Thomas, 2000; Coch, et al., 2005; Durston et al., 2002; Lackner et al., 2013; Lewis et al., 2006; Luna et al., 2002; Sanders et al., 2006; Stevens et al., 2009), gender (Newcorn et al., 2001), medication status (Diamond, Tannock, & Schachar, 1999; Pliszka, 1989; Tannock & Schachar, 1995), and household income (Stevens et al., 2009) are associated with attentional and impulse control, information on each of these factors were collected so that between-group variability within these factors and their relationship to the ERP components of interest could be explored. Intelligence as measured by the Verbal Comprehension composite index score (VCI) and the Perceptual Reasoning index (PRI) score of the Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV; Wechsler, 2003) was acquired through a file review of client records at the participating mental health agency. The Client Information Form (see *Appendix E)* was completed by the youth's parent and included questions regarding age, gender, medication currently taken, and household income (i.e., less than $25,000; 25,000-50,000; 50,000-$75,000; $75,000-$100,000; $100,000- $150,000; and more than $200,000).

Hypotheses

Given the mixed self-report and behavioural findings regarding the impact of comorbid anxiety on core symptoms of ADHD, and that this is the first study using ERPs to examine the impact of anxiety on attentional and impulse control in youth with ADHD, no directional hypotheses are made. Rather, this research is exploratory in nature and will explore the following non-directional hypotheses.

Attentional Control. Youth with ADHD+ANX will exhibit differential impairments in attentional control compared to youth with ADHD only as evidenced by the following:

(1) The EFP component will have significantly different amplitudes for attended target tones, and attended non-target tones.

(2) The N1 component will have significantly different amplitudes for attended target tones, and attended non-target tones.

(3) The P3b component will have significantly different amplitudes for attended target tones, and attended non-target tones.

Impulse Control. Youth with ADHD+ANX will exhibit differential impairments in impulse control compared to youth with ADHD only as evidenced by the following:

(1) The N2 component will have significantly different amplitudes for correct no-go trials, and go trials.

(2) The P3 component will have significantly different amplitudes for correct no-go trials, and go trials.

Results

Participant Characteristics

Participant demographic information by group (ADHD, ADHD+ANX) is displayed in Table 1.

Independent sample *t*-tests were used to analyze group differences for age, intelligence, and number of comorbid diagnoses. On average, participants with ADHD without anxiety were approximately one year younger (M = 12.47, SE = .175) than participants with ADHD+ANX (M = 13.36, SE = .339). This difference was significant, $t(65) = -2.36$, $p = .021$. In terms of intelligence, participants with ADHD without anxiety had higher VCI scores (M = 69.04, SE = 5.47) and PRI scores than participants with ADHD+ANX. Group differences did not reach significance ($t(54) = .556$, $p = .580$ and $t(49) = .361$, $p = .720$). Participants with ADHD without anxiety had significantly fewer comorbid diagnoses than participants with ADHD+ANX ($t(48.14) = -3.16$, $p = .003$). The most common comorbid diagnosis across groups was Oppositional Defiant Disorder.

The likelihood ratio test statistic was used to analyze group differences in gender, ADHD subtype, and income. Overall, there were more males than females in the sample. There were also more females with ADHD+ANX than ADHD without anxiety however, this difference was not significant, $L\chi^2$ (1) = 2.07, p = .188. Across both ADHD without anxiety and ADHD+ANX groups the Inattentive subtype of ADHD was most common. There was not a significant association between group and ADHD subtype, $L\chi^2$ (2) = 1.94, p = .380. Furthermore, no significant differences were found between groups on household income, $L\chi^2$ (6) = 3.73, p = .714.

Pearson's chi-square test was used to analyze group differences in medication status. No significant differences were found between groups, χ^2 (1) = .163, p = .686.

Behavioural Results

Selective Auditory Attention Task. A series of independent sample *t*-tests were conducted in order to examine group differences in percentage of accurate responses to AT, percentage of inaccurate responses to ANTs, and response time to AT during the selective auditory attention task. Table 2 displays the means of these variables by group. Participants with ADHD without anxiety had the same percentage of accurate responses to ATs as participants with ADHD+ANX, and as such, group differences were not significant, $t(60) = .038$, $p = .970$. Participants with ADHD without anxiety had a slightly higher percentage of inaccurate responses to ANTs than participants with ADHD+ANX; however, this difference was not significant, $t(60) = .125$, $p = .901$. Participants with ADHD without anxiety responded more quickly to ATs than participants with ADHD+ANX, however, this difference was not significant, $t(59) = -.350$, $p = .727$.

Go/No-Go Task. A series of independent sample *t*-tests were conducted in order to examine group differences in omission and commission errors during the go/no-go task, as well as response time for correct trials. Table 2 displays the mean omission and commission errors and response times of youth by group. Participants with ADHD without anxiety made more omission and commission errors than participants with ADHD+ANX, however, these differences did not reach significance, $t(61) = 1.40$, $p = .166$ and $t(61) = .635$, $p = .528$, respectively. Participants with ADHD without anxiety responded more quickly than participants with ADHD+ANX, however, this difference was not significant, $t(55.06) = -.398$, $p = .692$.

ERP Results

Selective Auditory Attention Task. Table 3 displays the mean amplitude and latency for all components of interest in the selective auditory attention task. Cases were excluded pairwise; thus, if a participant had a peak amplitude or latency missing for a particular analysis, their data were excluded only from calculations involving the component in which they had no score. Such a strategy allowed for maintaining a larger sample size in order to successfully detect effects. A factorial repeated-measures ANOVA was completed to examine the impact of group (ADHD vs. ADHD+ANX), electrode site (Fz, FCz, Cz), and condition (ATs vs. ANTs) on each of the components of interest (EFP amplitude and latency; N1 amplitude and latency; P3 amplitude and latency). If the assumption of sphericity was violated, degrees of freedom were adjusted using the Greenhouse-Geisser estimate when the estimate of sphericity was under .75. When estimates of sphericity were greater than .75, the Huynh-Feldt correction was used. Only significant main effects and interactions will be reported, with the exception of the primary hypotheses, in which all results will be reported. Where the primary hypotheses were supported, post-hoc paired sample *t*-tests were conducted, as well as correlational analyses in order to examine if age and number of comorbid diagnoses were related to effects. If significant associations were found, the ANOVA was re-run including the associated construct as a covariate (e.g., see age and *EFP Amplitude*).

***EFP Amplitude*.** A factorial repeated-measures ANOVA was completed to examine the impact of group (ADHD vs. ADHD+ANX), electrode site (Fz, FCz, Cz), and condition (ATs vs. ANTs) on EFP amplitude. Given that Mauchly’s test indicted that the assumption of sphericity had been violated for the main effect of site, $\chi^2(2) = 10.33$, $p = .006$, and condition x site, $\chi^2(2) = 13.05$, $p = .001$, degrees of freedom were corrected using Huynh-Feldt estimates of sphericity (ε

= .901, ε = .871). Significant main effects were found for electrode site, $F(1.80, 109.91) = 55.75$, $p < .001$, with smaller amplitudes found at Cz ($M = .520$, $SE = .178$), and larger amplitudes found at FCz ($M = 1.46$, $SE = .24$) and Fz ($M = 2.16$, $SE = .17$). A significant interaction was found for condition x site, $F(1.74, 106.31) = 4.95$, $p = .012$, indicating that smaller amplitudes were observed at Fz in response to ANTs ($M = 1.92.62$, $SE = .159$) compared to ATs ($M = 2.40$, $SE = .246$), while the opposite pattern of results was found at FCz and Cz, with larger amplitudes observed in response to ANTs ($M = 1.53$, $SE = .122$; $M = .591$, $SE = .093$), compared to ATs ($M = 1.39$, $SE = .430$; $M = .450$, $SE = .318$). A significant interaction was found for condition x group, $F(1, 61) = 5.25$, $p = .025$. This indicates that the condition (ATs vs. ANTs) had different effects on peak EFP amplitude depending on whether participants had ADHD without anxiety or ADHD+ANX. As seen in Figure 2, this interaction reflects that smaller peak EFP amplitudes were generated by ATs ($M = .898$, $SE = .440$) than ANTs ($M = 1.51$, $SE = .152$) for participants with ADHD without anxiety; this difference, however, did not reach significance, $t(30) = -1.09$, $p = .283$. The opposite pattern of results was found in participants with ADHD+ANX, with larger peak EFP amplitudes to ATs ($M = 1.93$, $SE = .433$) versus ANTs ($M = 1.18$, $SE = .150$). A post-hoc paired-sample *t*-test revealed this difference was significant, $t(31) = 3.51$, $p < .001$, and represented a medium to large effect size, $d = .49$. Correlational analyses indicated that peak EFP amplitudes were not significantly associated with number of comorbid diagnoses across sites or conditions. However, younger age was associated with increased EFP amplitudes to ATs at Fz ($r_s = -.332$, $p = .008$) as well as increased EFP amplitudes to ANTs at Fz ($r_s = -.380$, $p = .002$) and FCz ($r_s = -.368$, $p = .002$). Given significant group differences in age, as well as the association between the EFP component and age discussed above, the analysis was re-run, including age as a covariate. A significant interaction remained for condition x group, $F(1, 60) = 4.65$, $p = .035$.

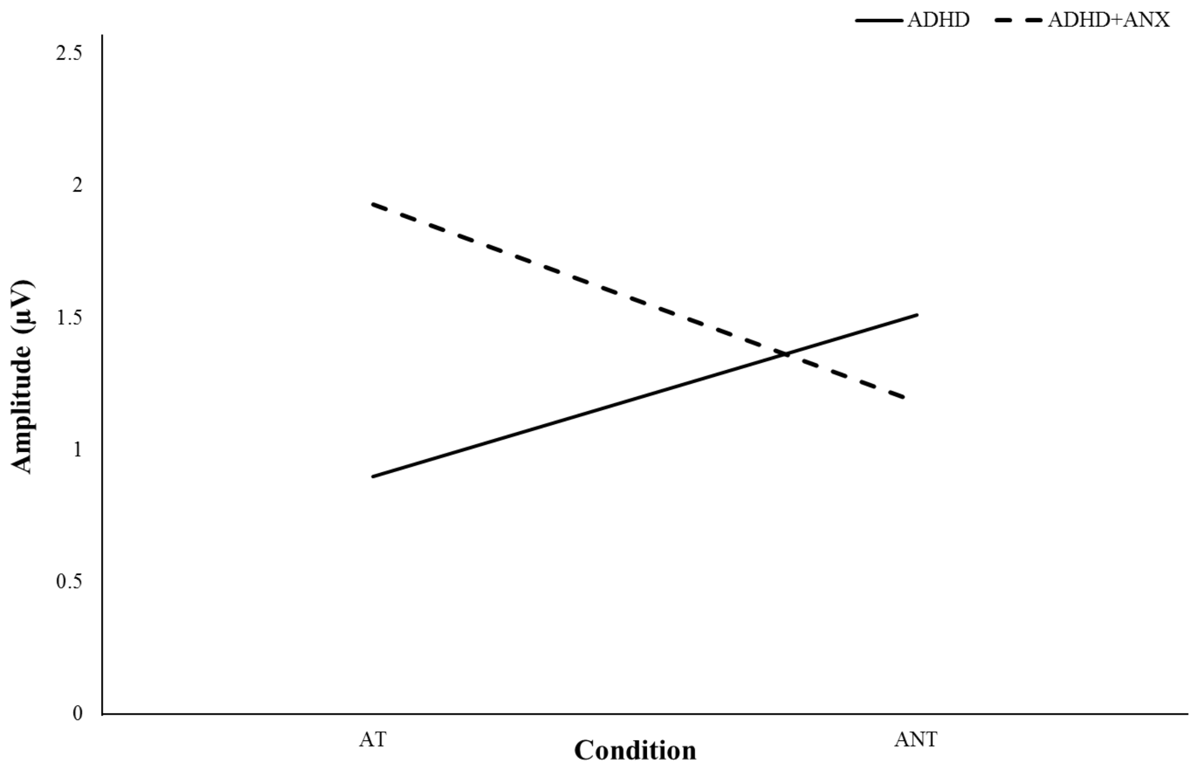

Figure 2: Peak attended-target and attended non-target EFP amplitudes in youth with ADHD without anxiety and ADHD+ANX.

EFP Latency. A factorial repeated-measures ANOVA was completed to examine the impact of group (ADHD vs. ADHD+ANX), electrode site (Fz, FCz, Cz), and condition (ATs vs. ANTs) on EFP latency. Given that Mauchly's test indicted that the assumption of sphericity had been violated for the main effect of site, $\chi^2(2) = 32.07$, $p < .001$, degrees of freedom were corrected using the Greenhouse-Geisser estimate of sphericity ($\varepsilon = .707$). Significant main effects were found for electrode site, $F(1.41, 86.28) = 8.75$, $p = .001$, with shorter latencies found at Cz ($M = 90.56$, $SE = 2.56$), and longer latencies found at FCz ($M = 97.68$, , $SE = 2.16$) and Fz

(M = 97.31, SE = 2.25). There was also a significant main effect of condition, $F(1, 61) = 18.91$, $p < .001$, with ATs generating shorter latencies overall (M = 88.68, SE = 2.85) than ANTs (M = 101.70, SE = 2.18). No significant interaction was found between condition and group, $F(1, 61) = .200$, $p = .656$.

N1 Amplitude. A factorial repeated-measures ANOVA was completed to examine the impact of group (ADHD vs. ADHD+ANX), electrode site (Fz, FCz, Cz), and condition (ATs vs. ANTs) on N1 amplitude. Given that Mauchly's test indicted that the assumption of sphericity had been violated for the main effect of site, $\chi^2(2) = 28.69$, $p < .001$, and condition x site, $\chi^2(2) = 40.25$, $p < .001$, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .727$, $\varepsilon = .674$). A significant interaction was found for condition x site, $F(1.35, 83.61) = 3.84$, $p = .041$, indicating that while smaller amplitudes were observed at Fz during the AT condition (M = -2.82, SE = .395) compared to FCz (M = -3.39, SE = .798) and Cz (M = -3.28, SE = .557), the opposite pattern of results were found in the ANT condition, with larger amplitudes observed at Fz (M = -2.57, SE = .241) compared to the FCz (M = -2.26, SE = .220) and Cz (M = -1.80, SE = .165). No significant interaction was found between condition and group, $F(1, 62) = 2.00$, $p = .163$.

N1 Latency. A factorial repeated-measures ANOVA was completed to examine the impact of group (ADHD vs. ADHD+ANX), electrode site (Fz, FCz, Cz), and condition (ATs vs. ANTs) on N1 latency. Given that Mauchly's test indicted that the assumption of sphericity had been violated for the main effect of site, $\chi^2(2) = 23.73$, $p < .001$, degrees of freedom were corrected using Huynh-Feldt estimates of sphericity ($\varepsilon = .784$). Significant main effects were found for electrode site, $F(1.57, 97.17) = 23.84$, $p = .001$, with longer latencies found at Fz (M = 155.51, SE = 2.30), and shorter latencies found at FCz (M = 149.38, , SE = 2.09) and Cz (M =

146.12, *SE* = 1.64). No significant interaction was found between condition and group, $F(1, 62) = .541$, $p = .465$.

P3b Amplitude. A factorial repeated-measures ANOVA was completed to examine the impact of group (ADHD vs. ADHD+ANX), electrode site (Fz, FCz, Cz), and condition (ATs vs. ANTs) on P3b amplitude. Given that Mauchly's test indicted that the assumption of sphericity had been violated for the main effect of site, $\chi^2(2) = 53.20$, $p < .001$, and condition x site, $\chi^2(2) = 37.20$, $p < .001$, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .622$, $\varepsilon = .676$). Significant main effects were found for electrode site, $F(1.25, 72.19) = 73.71$, $p < .001$, with the largest amplitudes found at Cz ($M = 2.68$, $SE = .350$), and smaller amplitudes found at FCz ($M = .850$, $SE = .366$) and Fz ($M = -.794$, $SE = .318$). Significant main effects were found for condition, $F(1, 58) = 56.45$, $p < .001$, with larger amplitudes overall for ATs ($M = 2.43$, $SE = .459$), and smaller amplitudes for ANTs ($M = -.602$, $SE = .234$). A significant interaction was found for condition x site, $F(1.35, 78.42) = 14.53$, $p < .001$, indicating that smaller differences in amplitudes were observed at Fz between ATs ($M = .167$, $SE = .492$) and ANTs ($M = -1.76$, $SE = .264$), while larger differences in amplitudes were observed at FCz between ATs ($M = 2.45$, $SE = .564$) and ANTs ($M = -.750$, $SE = .273$), and Cz between ATs ($M = 4.66$, $SE = .520$) and ANTs ($M = .699$, $SE = .240$). No significant interaction was found between condition and group, $F(1, 58) = .474$, $p = .494$.

P3b Latency. A factorial repeated-measures ANOVA was completed to examine the impact of group (ADHD vs. ADHD+ANX), electrode site (Fz, FCz, Cz), and condition (ATs vs. ANTs) on P3 latency. Given that Mauchly's test indicted that the assumption of sphericity had been violated for the main effect of site, $\chi^2(2) = 23.21$, $p < .001$, and condition x site, $\chi^2(2) = 6.56$, $p = .038$, degrees of freedom were corrected using Greenhouse-Geisser and Huynh-Feldt estimates of sphericity ($\varepsilon = .749$, $\varepsilon = .945$). No significant interaction was found between condition and group, $F(1, 58) = .434$, $p = .513$.

Go/No-Go Task. Table 4 displays the mean amplitude and latency for all components of interest in the go/no-go task. Cases were excluded pairwise; thus, if a participant had a peak amplitude or latency missing for a particular analysis, their data were excluded only from calculations involving the component for which they had no score. Such a strategy allowed for maintaining a larger sample size in order to successfully detect effects. Using SPSS software, a factorial repeated-measures ANOVA was completed to examine the impact of group (ADHD vs. ADHD+ANX), electrode site (Fz, FCz, Cz), and condition (correct go vs. correct no-go trials) on each of the components of interest (N2 amplitude and latency; P3 amplitude and latency). If the assumption of sphericity was violated, degrees of freedom were adjusted using the Greenhouse-Geisser estimate when the estimate of sphericity was under .75. When estimates of sphericity were greater than .75, the Huynh-Feldt correction was used. Only significant main effects and interactions will be reported, with the exception of the primary hypotheses, in which all results will be reported. Where the primary hypotheses were supported, post-hoc paired sample *t*-tests were conducted, as well correlational analyses to examine if age and number of comorbid diagnoses were related to effects (due to the presence of group differences).

***N2 Amplitude*.** A factorial repeated-measures ANOVA was completed to examine the impact of group (ADHD vs. ADHD+ANX), electrode site (Fz, FCz, Cz), and condition (go vs. no-go) on N2 amplitude. Given that Mauchly's test indicted that the assumption of sphericity had been violated for the main effect of site, $\chi^2(2) = 18.14$, $p < .001$, and condition x site, $\chi^2(2) = 22.99$, $p < .001$, degrees of freedom were corrected using Huynh-Feldt and Greenhouse-Geisser estimates of sphericity ($\varepsilon = .813$, $\varepsilon = .745$). Significant main effects were found for electrode site, *F*(1.63, 72.98) = 16.17, *p* < .001, with smaller amplitudes found at Cz (*M* = -4.32, *SE* = .53), and larger amplitudes found at FCz (*M* = -6.83, *SE* = .67) and Fz (*M* = -7.26, *SE* = .62). There was also a significant main effect of condition, *F*(1, 56) = 36.56, *p* < .001, with the go condition generating larger amplitudes overall (*M* = -6.35, *SE* = .522) than the no-go condition (*M* = -5.93, *SE* = .521). A significant interaction was found for condition x group, *F*(1, 56) = 4.40, *p* = .04. This indicates that the condition (go vs. no-go) had different effects on peak N2 amplitude depending on whether participants had ADHD without anxiety or ADHD+ANX. As seen in Figure 3 (below), this interaction reflects that there was a greater decrease in the amplitude between go (*M* = -6.85, *SE* = .808) and no-go conditions (*M* = -4.23, *SE* = .756) for the ADHD only group, which a post-hoc paired-sample *t*-test revealed was significant, *t*(27) = -6.39, *p* < .0001, and represented a large effect size, *d* = .67. In contrast, N2 amplitudes were similar across go (*M* = -7.38, *SE* = .781) and no-go (*M* = -6.10, *SE* = .730) conditions for ADHD+ANX, although a post-hoc paired-sample *t*-test revealed this difference was significant, *t*(29) = -2.59, *p* = .015, and represented a small effect size, *d* = .29. Correlational analyses indicated that peak N2 amplitudes were not significantly associated with age or additional comorbid diagnoses across sites or conditions.

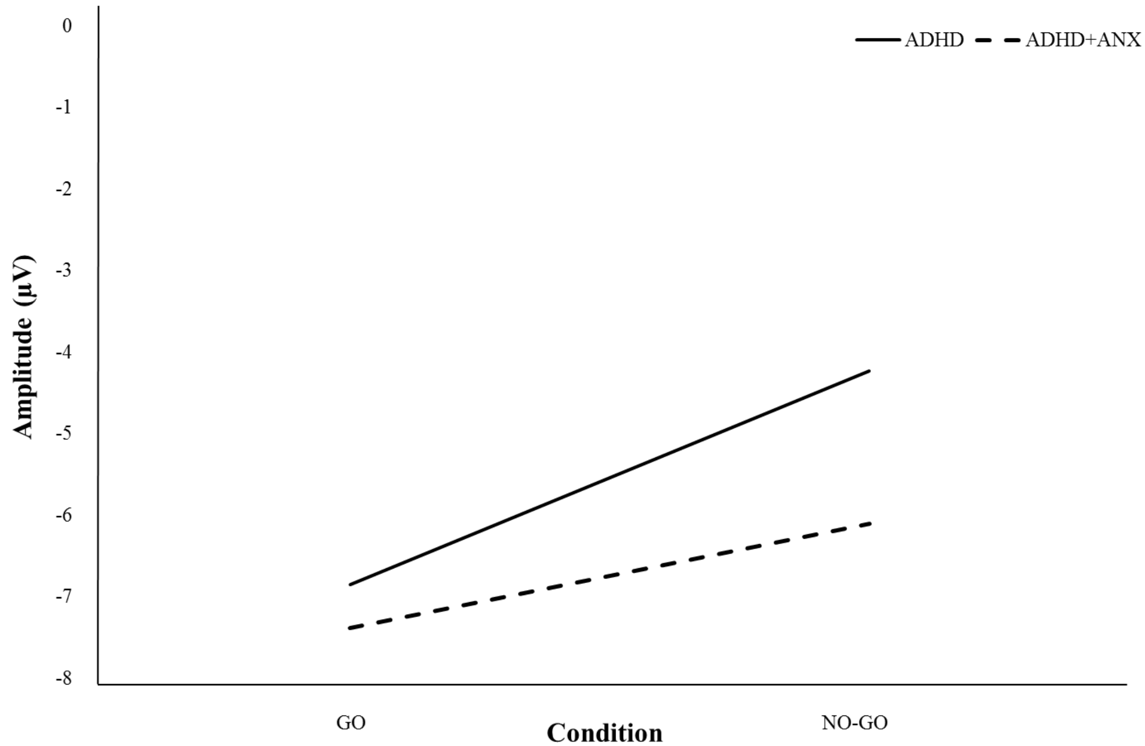

Figure 3: Peak go and no-go N2 amplitudes in youth with ADHD without anxiety and youth with ADHD+ANX.

N2 Latency. A factorial repeated-measures ANOVA was completed to examine the impact of group (ADHD vs. ADHD+ANX), electrode site (Fz, FCz, Cz), and condition (go vs. no-go) on N2 latency. Given that Mauchly's test indicted that the assumption of sphericity had been violated for the main effect of site, $\chi^2(2) = 21.76$, $p < .001$, and condition x site, $\chi^2(2) = 9.17$, $p = .01$, degrees of freedom were corrected using the Greenhouse-Geisser and Huynh-Feldt estimates of sphericity ($\varepsilon = .754$, $\varepsilon = .908$). Significant main effects were found for electrode site, $F(1.51, 84.42) = 21.74$, $p < .001$, with shorter latencies found at Cz (*M* = 261.60, *SE* = 6.15), and longer latencies found at FCz (*M* = 275.62, , *SE* = 5.96) and Fz (*M* = 286.98, *SE* = 5.31). No significant interaction was found between condition and group, $F(1, 56) = .067$, $p = .797$.

P3 Amplitude. A factorial repeated-measures ANOVA was completed to examine the impact of group (ADHD vs. ADHD+ANX), electrode site (Fz, FCz, Cz), and condition (go vs.

no-go) on P3 amplitude. It should be noted that the P3 component could not be scored on one or more sites in $n = 12$ youth with ADHD without anxiety, and $n = 9$ youth with ADHD+ANX. Given that Mauchly's test indicted that the assumption of sphericity had been violated for the main effect of site, $\chi^2(2) = 34.12$, $p < .001$, and condition x site, $\chi^2(2) = 12.55$, $p = .002$, degrees of freedom were corrected using the Greenhouse-Geisser estimates of sphericity ($\varepsilon = .578$, $\varepsilon = .723$). A significant main effect was found for electrode site, $F(1.16, 31.20) = 26.11$, $p < .001$, with larger amplitudes found at Cz ($M = 2.70$, $SE = .75$), and smaller amplitudes found at FCz ($M = .110$, $SE = .734$) and Fz ($M = -2.18$, $SE = .76$). A significant main effect was also found for condition, $F(1, 27) = 33.94$, $p < .001$, with larger amplitudes overall in the no-go condition ($M = 1.95$, $SE = .80$) compared to the go condition ($M = -1.54$, $SE = .61$). No significant interaction was found between condition and group, $F(1, 27) = .704$, $p = .409$.

P3 Latency. A factorial repeated-measures ANOVA was completed to examine the impact of group (ADHD vs. ADHD+ANX), electrode site (Fz, FCz, Cz), and condition (go vs. no-go) on P3 latency. Given that Mauchly's test indicted that the assumption of sphericity had been violated for the main effect of site, $\chi^2(2) = 29.65$, $p < .001$, and condition x site, $\chi^2(2) = 28.21$, $p = .002$, degrees of freedom were corrected using the Greenhouse-Geisser estimates of sphericity ($\varepsilon = .595$, $\varepsilon = .602$). A significant interaction was found for condition x site, $F(1.20, 32.49) = 4.60$, $p = .033$, indicating that shorter latencies were observed at Cz during the no-go condition ($M = 346.62$, $SE = 8.96$) compared to the go condition ($M = 362.78$, $SE = 10.27$), while the opposite pattern of results was found at Fz and FCz, with longer latencies observed during the no-go condition ($M = 363.34$, $SE = 11.09$; $M = 362.19$, $SE = 10.17$), compared to the go condition ($M = 354.19$, $SE = 11.28$; $M = 353.55$, $SE = 10.30$). No significant interaction was found between condition and group, $F(1, 27) = .263$, $p = .612$.

Discussion

The aim of the current study was to explore if neural indices of attentional and impulse control differ in youth with ADHD without anxiety and ADHD+ANX, as previous research using self-report and behavioural measures has been mixed.

Attentional Control

Significant differences between youth with ADHD without anxiety and youth with ADHD+ANX were found for EFP amplitudes. Specifically, youth with ADHD without anxiety showed smaller EFP amplitudes in response to ATs than ANTs, whereas youth with ADHD+ANX showed the opposite pattern. Given that larger EFP amplitudes to attended stimuli and smaller EFP amplitudes to unattended stimuli are associated with better attentional control (Jonkman et al., 2004; Jonkman et al., 1997; Stevens et al., 2009; Lackner et al., 2013), these results suggest that the addition of anxiety in youth with ADHD is associated with enhanced early attentional allocation in comparison to youth with ADHD without anxiety. This is the first known study to show this relationship at the neurocortical level.

The present findings are consistent with behavioural research conducted by Vloet et al. (2010) comparing youth with ADHD without anxiety to youth with ADHD+ANX. These researchers found that while youth with ADHD+ANX exhibit challenges compared to controls without ADHD or anxiety on a variety of neuropsychological tasks, their performance was better than youth with ADHD without anxiety, particularly in measures of set-shifting and divided attention (Vloet et al., 2010).

We believe that the present findings may be partially explained by attentional biases in the ADHD+ANX group. Attentional biases toward threat or negative stimuli are well documented for both anxious adults (e.g., Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg,

& van IJzendoorn, 2007; Veljaca, & Rapee, 1998) and youth (e.g., Puliafico & Kendall, 2006; Roy et al., 2008). For example, a study conducted by Roy and colleagues (2008) examined attentional bias toward threatening faces during a visual probe task in which youth had to press a button to indicate the location of a probe after pairs of mismatched angry, happy, and neutral faces were presented. Compared to healthy controls, youth aged 7 to 18 with anxiety had significantly shorter reaction times when probes were presented in the location where an angry face had been presented, indicating that youth with anxiety demonstrated a greater attentional bias toward threatening stimuli. This study demonstrates that this attentional bias is pervasive across a variety of anxiety disorders in youth, including generalized anxiety disorder, social anxiety disorder, and separation anxiety disorder. 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 threat. Although Richards and colleagues (2014) provide evidence for this in the context of eye-tracking studies conducted with adults with anxiety, it is possible that a similar principle may account for the pattern of EFP results observed in the present study. Specifically, the addition of anxiety in youth allowed for the rapid processing of task-relevant stimuli (ATs) while filtering out non-target tones (ANTs). While ATs are not "threatening" per se, they do indicate to youth that a task response is required. In youth with anxiety who may be worried about task performance (Eysenck & Calvo, 1992), the processing of ATs may be prioritized as they serve to warn that the execution of a correct response is required.

While this interpretation and the current results support the theory that the presence of anxiety in youth with ADHD is associated with enhanced attention, this finding is at odds with research that has shown greater impairment in youth with ADHD+ANX when compared to youth with ADHD or anxiety alone in a variety of social, academic, and cognitive domains (Bowen et al., 2008; Jensen et al., 2001; Mikami et al., 2011; Pliszka, 1989; Pliszka, 1992). As noted by Rodríguez, González-Castro, García, Núñez, and Alvarez (2014), insights into why this occurs may be reconciled with attentional control theory (Derakshan & Eysenck, 2009).

Attentional control theory postulates that anxiety disrupts the balance between top-down, controlled attentional processes and bottom-up, stimuli-driven attentional processes by favouring the latter (Derakshan & Eysenck, 2009). Support for this theory comes from the aforementioned research that demonstrates that anxiety is associated with attentional biases toward threat or negative stimuli (e.g., Bar-Haim et al., 2007; Puliafico & Kendall, 2006; Roy et al., 2008; Veljaca, & Rapee, 1998). As such, this theory suggests that individuals with anxiety are less able to recruit top-down, efficient, goal-driven attentional processes, and instead favour bottom-up, stimuli-driven attentional processes in the presence of threat and/or negative stimuli, which in turn negatively impacts functioning (Derakshan & Eysenck, 2009; Rodríguez et al., 2014). Empirical support for this theory can be observed in studies in which anxiety impairs performance when the task to be performed involves threatening and/or negative stimuli (Bar-Haim et al., 2007). Many of these studies employ the emotional Stroop task, in which participants must name the colour of emotionally-charged and neutral words (Bar-Haim et al., 2007). During this task, individuals with anxiety are slower to name the colour presented with an emotionally-charged word, which suggests impaired attentional control in the presence of threat and/or negative stimuli (Derakshan & Eysenck, 2009). Further support for attentional control theory comes from a recent study conducted by Susa, Pitică, Benga, & Miclea (2012) which found that youth aged 9 to 14 who rated high in anxiety also self-reported low levels of attentional control and exhibited a greater attentional bias to angry faces during a visual-probe task (described above). Although similar studies have yet to be conducted in youth with ADHD+ANX, Pliszka (1989) found that youth aged 6 to 12 with ADHD+ANX displayed longer reaction times as distractor conditions became more challenging during a working memory task. Therefore, if the selective auditory attention task used in the present study incorporated more challenging conditions with greater distractions, we may have found deficits in attentional processes in youth with ADHD+ANX as tasks become more complex.

No significant differences were found between ADHD without anxiety and ADHD+ANX groups on measures of participant behavioural response during the selective auditory attention task (e.g., percent accurate response to AT, percent inaccurate response to ANT, response time). While smaller EFP amplitudes to ATs in youth with ADHD compared to typically developing controls has been associated with more errors of omission and commission during selective attention tasks (Jonkman et al., 2004; Jonkman et al., 1997), the difference in EFP amplitudes between groups in the current study may not have been of the same magnitude as that with typically developing controls. It is also possible that no significant differences were found because task difficulty was designed to be at a level that promoted successful performance, such that ERPs could more confidently be attributed to differences in neural processes, rather than differences in task performance. As such, participants may have uniformly performed well on the task, limiting the ability to detect group differences.

While significant group differences were found for EFP amplitudes, no significant differences were found between groups in terms of the later N1 and P3b components. The current N1 findings are consistent with Lackner et al. (2013) and Jonkman et al. (1997) who compared youth with working memory challenges and youth with ADHD to age-matched controls. However, the lack of P3b findings is particularly surprising given that decreased P3b amplitudes to target stimuli are fairly consistently found in youth with ADHD, indicating poor attentional resource allocation (Janssen et al., 2016; Johnstone, Barry, & Clark, 2013; Kratz et al., 2011; Satterfield et al., 1994). While P3b amplitudes are less often explored in the anxiety literature, research that has been conducted suggests that anxiety is associated with larger P3b amplitudes and shorter P3b latencies to target stimuli during an audio-oddball task, suggestive of better attentional control (Daruna et al., 1991). The present study's P3b findings are consistent with Klorman and colleagues's (2002) study examining P3b amplitudes in youth aged 7 to 13 with ADHD compared to age-matched controls without ADHD within the context of a visual-oddball task. This absence of a P3b effect was attributed to the simplicity of the task, however, this explanation is at odds with prior research demonstrating increased P3b amplitudes in youth with ADHD using similar oddball paradigms (i.e., Janssen et al., 2016; Satterfield et al., 1994). Gomes et al. (2012) also did not find a P3b effect in youth with ADHD using a selective auditory attention task. Compared to typically developing youth, youth aged 7 to 13 with ADHD elicited similar P3b amplitudes to ATs, while both groups did not elicit P3b amplitudes to unattended targets (Gomes et al., 2012). This led the researchers to conclude that youth with ADHD have adequate ability in the domain of selective attention.

In sum, the addition of anxiety in youth with ADHD appears to enhance very early attentional processing in a relatively simple, non-affect laden task. This may reflect an early occurring attentional bias or hypervigilance in processing information. While this may be interpreted as an enhancement, it is possible that when information presented is more complex or affectively laden, this processing style may result in longer latencies and decreased allocation of attentional resources. To further explore this hypothesis, future research should explore the novelty P3a when comparing youth with ADHD+ANX and youth with ADHD without anxiety.

The novelty P3a is elicited by classification of highly deviant, task-irrelevant auditory and visual stimuli, and has been shown to be greater in youth with anxiety (Reeb-Sutherland et al., 2009). For example, using a task in which participants read a story while simultaneously presented with auditory stimuli they were told to ignore (i.e., standard tones, deviant tones, and novel sounds such as a door closing or dog barking), Reeb-Sutherland and colleagues (2009) found that youth aged 13 to 16 who displayed larger P3a amplitudes to novel sounds were more likely to have a history of anxiety disorders, compared to age-matched controls with lower P3a amplitudes. The researchers concluded that poor attentional control skills in youth with anxiety, whose attention is frequently drawn to distractions and/or threatening information, are in turn more susceptible to negative affect. Interestingly, P3a amplitudes to novel stimuli may be diminished in youth with ADHD without anxiety, which is consistent with preliminary research with adults (Marzinzik et al., 2012).

Impulse Control

Significant differences between youth with ADHD without anxiety and youth with ADHD+ANX were found for N2 amplitudes. Specifically, youth in both groups showed similar N2 amplitudes in the go condition, however, in the no-go condition, youth with ADHD without anxiety showed smaller N2 amplitudes compared to youth with ADHD+ANX. This suggests that the addition of anxiety in youth with ADHD is associated with a greater ability to recruit cognitive resources towards impulse control. This is the first study to show this relationship in youth with ADHD+ANX compared to ADHD without anxiety. It is also consistent with previous research demonstrating that N2 amplitudes for tasks requiring impulse control are significantly smaller in youth with ADHD relative to youth without ADHD (Dimoska et al., 2003; Johnstone, et al., 2009; Liotti et al., 2010; Liotti et al., 2010) and with literature demonstrating significantly larger no-go N2 amplitudes than youth with anxiety compared to youth without anxiety (Hum et al., 2013a). These findings are also consistent with previous research using behavioural, 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; March et al., 2000; Pliszka, 1989; Pliszka, 1992).

There are a variety of theories regarding why impulse control may be enhanced in the presence of anxiety (e.g., see Rodríguez et al., 2014). Some researchers draw on Quay's theory (1988) regarding the Behavioural Inhibition System (BIS) and the Behavioural Activation System (BAS), suggesting that while ADHD may be related to deficits in the BIS, which in turn results in poor impulse control, anxiety is associated with an overactive BIS, which serves to enhance the BIS of youth with ADHD+ANX (Rodríguez et al., 2014). Alternatively, Eysenck & Calvo's Processing Efficiency Theory (1992) suggests that while self-preoccupation and worry about performance will impair the execution of challenging tasks in individuals with anxiety, the desire to do well may serve to motivate and enhance performance in individuals with ADHD+ANX during simple tasks, thus resulting in better impulse control. This theory may help explain the current findings. More specifically, 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 during the current study's simple go/no-go task. However, we suspect that anxiety may negatively impact impulsivity and performance during more challenging tasks. 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).

Youth with ADHD+ANX also demonstrated similar N2 amplitudes regardless of trial type. This parallels Hum et al. (2013a) findings that youth with anxiety exhibited similar N2 amplitudes across go and no/go conditions, while control youth exhibited greater no-go N2 amplitudes compared to go N2 amplitudes. Hum and colleagues (2013a) interpreted these findings as reflective of possible challenges with impulse control due to hypervigilance in youth with anxiety. Hypervigilance can be defined as a heightened sensitivity to environmental cues that serves to ensure one is ready to detect and act on threatening stimuli in the environment (Beck & Clark, 1997). It is distinct from attentional biases toward threat, as hypervigilance exists in the presence *or* absence of threat, and involves consistently scanning and monitoring the environment for potential dangers (Richards et al., 2014). While hypervigilance has likely served as an important survival mechanism throughout evolution, research suggests that higher levels of hypervigilance in modern society are associated with anxiety (e.g., Richards et al., 2014). In support of this, research demonstrates that youth with anxiety exhibit heightened levels of hypervigilance (Seefeldt, Krämer, Tuschen-Caffier, & Heinrichs, 2014). For example, using a visual probe task similar to those discussed above, Seefeldt and colleagues (2014) found that youth aged 8 to 12 with social anxiety (who have anxiety induced in the experiment) will first fixate on angry faces at a much higher rate than age-matched controls without anxiety when presented with angry-neutral pairs. Although the current study did not include threatening information, the addition of anxiety in youth with ADHD may have resulted in hypervigilance during the task. As such, youth with ADHD+ANX not only recruited more cortical resources during the task compared to youth with ADHD without anxiety, they also recruited similar amounts of cognitive resources despite trial type, reflecting hypervigilance to all cue conditions.

The current study also found a main effect of condition, with N2 amplitudes being significantly greater in the go rather than no-go condition across both groups. This is the opposite from what would be expected; given that greater N2 amplitudes are suggestive of greater activation of impulse control, it was anticipated that the no-go condition would elicit the largest N2 response. 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). In regards to ADHD, although Groom et al. (2010) generally found larger N2 amplitudes elicited in the no-go compared to the go condition, the researchers found the opposite pattern of results in only one condition (the baseline condition), and only for youth with ADHD using medication (youth with ADHD who were not on medication did not show this effect). Firstly, many youth in the present study's sample were being treated with medication (ADHD without anxiety, $n = 14$; ADHD+ANX, $n = 12$), which may have contributed to the same pattern of results found in Groom et al. (2008) study. Perhaps more importantly, like the Groom et al. (2008) baseline condition, the incentive to perform well in the current study's go/no-go task was low. The present study's no-go task paralleled Groom and colleagues (2010) baseline condition, as points were both rewarded and lost for correct and incorrect responses, respectively. Notably, Groom et al. (2010) found that the reward condition was associated with increased no-go N2 amplitudes in youth with ADHD, indicating that incentive is related to recruiting greater cortical resources toward impulse control 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 to motivate youth to activate impulse control processing at an optimal level. Therefore, future research should explore if stronger incentives, specifically greater rewards for correct responses, are associated with larger no-go than go N2 amplitudes in youth with ADHD, indicating stronger activation of impulse control processing.

No significant group differences were found for the P3 component. Many youth in the present study's sample did not generate a discernable P3 waveform. Therefore, for many participants across both groups, the P3 component could not be included in the analyses, which may have resulted in a loss of power to detect effects. As with the N2, P3 amplitudes for tasks requiring impulse control have been found to be significantly smaller in youth with ADHD relative to youth without ADHD (Liotti et al., 2005; Liotti et al., 2010; Groom et al., 2010; Rodriguez & Baylis, 2007), suggestive of weaker activation of impulse control. Although studied far less, anxiety has been associated with the opposite effect, with larger P3 amplitudes generated during go/no-go tasks (Sehlmeyer et al., 2010). The absence of the P3 across both groups in the current study suggest that while the current study's sample differs in earlier stages of impulse control, youth with ADHD, regardless of anxiety status, demonstrate similar impairments in later stages of processing related to impulse control.

It is interesting that a discernable P3 waveform was not generated for a number of youth in the present study. This finding is consistent with studies by Groom et al. (2008; 2010), Lamm et al. (2014), and Sehlmeyer et al. (2010). However, other studies have found a clear P3 waveform in samples of youth with ADHD (Johnstone et al., 2009; Rodriguez & Baylis, 2007) and anxiety (Hum et al., 2013a; 2013b; Lewis et al., 2008). One reason that the current study did not find a clear P3 waveform in the go/no-go task is that the present study's go/no-go task varied considerably from those used in previous literature with both ADHD (Johnstone et al., 2009; Rodriguez & Baylis, 2007) and anxiety (Hum et al., 2013a; 2013b; Lewis et al., 2008). For example, Johnstone et al. (2009) go/no-go task incorporated a "warning" stimulus before each go or no/go stimulus was presented. Go/no-go tasks utilized in studies with youth with anxiety frequently incorporate emotional stimuli in order to test if neural processes are affected by emotional regulation (Hum et al., 2013a; 2013b; Lewis et al., 2008). For example, while gender may be the cue used to signal go or no-go trials, facial expressions will vary to depict angry, calm, and happy emotions (Hum et al., 2013a; 2013b; Lewis et al., 2008). Given these task discrepancies, as with attentional control, future research examining the impact of comorbid anxiety on impulse control in youth with ADHD should use tasks that incorporate negative emotional stimuli.

Limitations & Directions for Future Research

The current study enhances our understanding of the impact of anxiety on core symptoms of ADHD (attentional control, impulse control) but has a number of limitations that will be important to address in future research. To begin, the current study utilized a structured diagnostic interview to identify the presence of anxiety. It is possible that the impact of anxiety on core ADHD symptoms may differ depending on the severity of anxiety symptoms, a construct that cannot be assessed using a categorical measure, such as the MINI-KID. The addition of a continuous measure, such as the Multidimensional Anxiety Scale for Children - Self Report (MASC 2-SR; March, 2012) in future research would help to clarify the role of anxiety severity and would also increase the power to measure the impact of anxiety on ERP components in statistical analyses (e.g., MacCallum, Zhang, Preacher, & Rucker, 2002).

The addition of a typically developing control group, as well as a group with anxiety without ADHD, would further deepen and developmentally contextualize the findings of the present study. For example, this would help to determine if the patterns of enhanced attentional control and impulse control seen in the ADHD+ANX groups are similar to those of typically developing peers and/or their counterparts without ADHD. This design might also help address the question of whether or not anxiety ameliorates core ADHD symptoms, or if there continue to be specific impairments that need to be addressed, noting that these limitations may differ from ADHD without anxiety.

Finally, comparing the results of the present study with the extant literature, two key questions have come to the forefront. First, are there differences in terms of attentional control and impulse control in hot and cold contexts? Zelazo's Iterative Reprocessing Theory (2015) postulates that depending on the context, executive functioning skills can be conceptualized along a continuum of "hot" and "cold." Although both hot and cold executive functions are considered top-down processes involved in goal-directed behaviour, hot executive functions are employed in situations linked to emotion, approach-avoidance behaviour, and behaviour related to reward and/or punishment. In contrast, cold executive functions are employed in situations that are more cognitive in nature. As such, they do not include an affective component. The current study focused on executive functioning processes in cold contexts. While enhanced attention and impulse control were noted in the comorbid ADHD+ANX group, it is possible that relations may differ for hot contexts. This would be an interesting question for future investigation, and one that might wish to incorporate source localization techniques in order to examine how anxiety impacts the brain within hot and cold contexts.

Second, do the neurological processing patterns found in youth with ADHD+ANX differ depending on the complexity of the information to be processed? It may be possible that the relative simplicity of the present study's tasks, including very specific task instruction, allowed for enhanced attentional and impulse control processes in youth with ADHD+ANX. However, as tasks increase in complexity and length, require multiple decisions, and do not come with explicit direction, it may be possible that youth with ADHD+ANX exhibit substantial impairments with regards to attentional and impulse control processing.

Clinical Implications

From a clinical standpoint, these findings support the view that ADHD+ANX may be a qualitatively distinct diagnostic condition from ADHD without anxiety (Jensen & Cantwell, 1997). In terms of diagnosis and treatment, it may be important to consider that attentional control and impulse control challenges may be less pronounced in this population, but still may be associated with heightened levels of impairment. As noted above, it will be important to look at the role of affective valence and complexity of information to be processed to specifically understand the relation between these ADHD core symptoms and situational demands. 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. Mindfulness interventions may be one such treatment given the centrality of attentional control. Mindfulness is the practice of focusing awareness on the present moment, while acknowledging and accepting feelings, thoughts, and bodily sensations (Sanger & Dorjee, 2015). It directly targets attentional control in that it requires one to intentionally focus and refocus their attention on the cognitions, emotions, and physiological sensations experienced on a moment-to-moment basis (Sanger & Dorjee, 2015). Mindfulness also emphasizes detached observation; awareness of one’s internal experience (i.e., cognitions, emotions, and physiological sensations) without judgment, and as a passing event. This detachment is theorized to aid in both recognizing and coping with distress, rather than impulsively reverting to former, poor coping strategies. In this way, mindfulness promotes impulse control (Baer, 2009). Studies to date suggest that mindfulness is indeed associated with parent-reported improvements in attention (Bögels, Hoogstad, van Dun, de Schutter, & Restifo, 2008) and impulsivity in youth with ADHD (van der Oord, Bögels, & Peijnenburg, 2011), however, these studies have yet to address how comorbid anxiety may impact these findings, and thus future research is needed in this area.

Conclusion

In conclusion, this is the first known study to analyze patterns of neural activity in order to explore the impact of anxiety on attentional and impulse control processes in youth with ADHD. 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 differences between these two groups may lie in the earliest stages of neural processing. The current study contributes to progress in understanding the neurological underpinnings of attentional and impulse control in youth with ADHD+ANX, which may help to inform targets for intervention in these highly comorbid conditions.

Table 1

Demographic Information

Group	ADHD (n = 34)	ADHD+ANX (n = 33)
Intelligence		
WISC Verbal Comprehension	M = 69.04, SE = 5.47	M = 64.67, SE = 5.63
WISC Perceptual Reasoning	M = 65.08, SE = 6.40	M = 61.78, SE = 6.52
Age	M = 12.47, SE = .175**	M = 13.36, SE = .339**
ADHD Subtype		
Inattentive	21	18
Hyperactive/Impulsive	1	0
Combined	12	15
Gender		
Male	31	26
Female	3	7
Medication		
Takes medication	14	12
Does not take medication	20	21
Household Income		
Less than $25,000	2	3
$25,000 - $50,000	5	4
$50,000 - $75,000	4	6
$75,000 - $100,000	5	2
$100,000 - $150,000	8	10
$150,000 - $200,000	0	1
More than $200,000	6	5
Number of Comorbid Diagnoses		
Depression	7	15
Bipolar Disorder (I or II)	1	4
Oppositional Defiant Disorder	9	17
Conduct Disorder	1	1
Tic Disorder	1	4
Autism	2	5
Total	21*	46*

Notes: M = Mean, SE = Standard Error
*p < .01. **p < .05.

Table 2

Behavioural Results

	ADHD *M (SE)*	**ADHD+ANX** *M (SE)*	***t***	***p***
Selective Auditory Attention Task				
Accuracy (% of AT responded to)	85.44 (2.52)	85.31 (2.44)	.038	.970
Errors (% of ANT responded to)	12.22 (5.02)	11.39 (4.36)	.125	.901
Response Time to AT	547.22 (12.59)	553.54 (12.92)	-.350	.727
Go/No-Go				
Omission Errors (incorrect Go)	22.20 (4.68)	14.94 (2.53)	1.40	.166
Commission Errors (incorrect No-Go)	40.50 (2.89)	37.97 (2.75)	.635	.528
Response Time to Go	364.25 (5.29)	368.02 (7.86)	-.398	.692

Notes: M = Mean, SE = Standard Error

Table 3

Mean Amplitude and Latency for the Selective Auditory Attention Task by Condition, and Condition X Group Interaction

	AT		**ANT**		**Condition X Group**	
Component	**ADHD** *M (SE)*	**ADHD+ANX** *M (SE)*	**ADHD** *M (SE)*	**ADHD+ANX** *M (SE)*	***F***	***p***
EFP						
Amplitude	.898 (.440)	1.93 (.433)	1.51 (.152)	1.18 (.150)	4.76	.033
Latency	90.97 (4.07)	86.381 (4.00)	102.65 (.3.10)	100.74 (3.05)	.200	.656
N1						
Amplitude	-3.90 (.759)	-2.43 (.759)	-2.16 (.264)	-2.26 (.264)	2.00	.163
Latency	146.29 (3.85)	150.40 (3.85)	152.30 (2.60)	152.33 (2.60)	.541	.465
P3b						
Amplitude	2.48 (.670)	2.37 (.627)	-.823 (.342)	-.328 (.320)	.474	.494
Latency	391.88 (12.21)	382.38 (11.42)	416.18 (13.18)	390.34 (12.33)	.434	.513

Notes: M = Mean, SE = Standard Error

Table 4

Mean Amplitude and Latency for Go/No-Go Task by Condition, and Condition X Group Interaction

	Go		**No-Go**		**Condition X Group**	
Component	**ADHD** *M (SE)*	**ADHD+ANX** *M (SE)*	**ADHD** *M (SE)*	**ADHD+ANX** *M (SE)*	***F***	***p***
N2						
Amplitude	-6.85 (.808)	-7.38 (.781)	-4.23 (.756)	-6.10 (.730)	4.40	.040
Latency	279.63 (8.56)	268.80 (8.23)	281.92 (8.42)	268.583 (8.10)	.067	.797
P3						
Amplitude	-.626 (.912)	-2.44 (.822)	3.36 (1.17)	.542 (1.06)	.704	.409
Latency	352.74 (14.58)	360.94 (13.15)	347.03 (13.60)	367.73 (12.26)	.263	.612

Notes: M = Mean, SE = Standard Error

Appendix A: RESEARCH STUDY CONSENT AGREEMENT MMA: PARENT CONSENT

Research Study Consent Agreement
MMA: Parent Consent

Title of Research Project:
Enhancing Emotion Regulation in Youth with Self-Regulation Disorders Through Integra Mindfulness Martial Arts

We would like to invite you and your child to participate in a research study that will help us better understand the benefits of Integra Mindfulness Martial Arts (MMA) for youth who struggle with challenges with their behaviour, anxiety, or mood. This study is being conducted for Integra by Dr. Karen Milligan, Assistant Professor in the Department of Psychology at Ryerson University.
<u>Before you give consent, it is important to read the following information and to ask questions to ensure that you understand what you and your child will be asked to do.</u>

Purpose of the Study: Integra is dedicated to developing and evaluating treatment for children and youth with learning disabilities and mental health issues. MMA is one of the programs that we have developed. Our previous research has shown that MMA results in positive gains for youth in terms of behaviour, anxiety, flexibility, and impulse control. We are interested in understanding more about how MMA impacts youth, particularly in terms of emotion regulation. More specifically, we will be examining if there are brain-based changes in emotion regulation that may support youth in making positive mental health gains.

Description of the Study: Participation will involve the following:
Youth
A session (approximately 2.5 to 3 hours) will be 3 times during the MMA program and at 3 month follow-up. We will collect information on the electrical activity in your child's brain using electroencephalography (EEG). This will help us understand how brainwaves remain stable over time and relate to emotion and behaviour improvements youth make in MMA. To record brain activity, a lycra stretch cap (similar to a bathing cap)" will be placed over your child's head. The brain sends out tiny amounts of electricity at all times, and the sensors in the cap pick up these electric signals when they reach your child's skin. The sensors rest on your child's scalp and record what's going on under the surface. A small amount of electrogel is also placed in each sensor in order to make a connection between the sensor and surface of the scalp. Your child can see this cap before deciding whether to participate or not. It takes about 5-10 minutes to fit and apply the cap. The cap is 100% safe, and there is no possibility of electricity or any other substance (except mild dampness) passing from the net to your child. Youth will complete 5 short computer tasks in concert with the EEG. This will include tasks that examine

changes in attention, impulse control, and psychological flexibility. You will also be asked to complete an interview about your emotions and behaviour.


Parents
Parents will be asked to complete an interview about their child's behaviour and emotions at the beginning of the study. They will also be asked to complete 2 questionnaires (10 minutes) four times during MMA either online or paper (your choice). For example, we will ask you to rate how true specific behaviour and emotion statements are about your child. For example:

- Considerate of other people's feelings
- Loses temper often

Integra File Review
As part of the study, we would like to collect information about your child's learning disability and mental health. As such, we will ask you if you would consent for us to access the most recent psychoeducational assessment completed with your child and any parent or youth behaviour questionnaires completed at Integra (e.g., Intake forms, Strength and Difficulties Questionnaire). We would also like to access data collected as part of MMA (e.g., attendance records, homework). We will review these records onsite at Integra and no identifying information will be taken off-site.

Incentives to Participate: Your child will receive $25 at the end of each research testing session to cover costs associated with travel and time. If your child decides to discontinue the study or does not attend a testing session, they will only be paid for the testing sessions they attend.

What is Experimental in this Study? All of the tasks and questionnaires used in this study have been used in previous research with children and youth.

Risks or Discomforts: There is minimal risk associated with participation in the study. *While this research study is separate and distinct from the MMA treatment that is being administered by Integra. Ryerson assumes no responsibility for risks involved in participation in the MMA treatment.*

The following minimal risks may be experienced as part of participation in the research study.

- The EEG cap can become a little uncomfortable. If your child feels the discomfort level is too high, we will remove the cap immediately upon your child's request.
- Your child's hair will be messy as a result of wearing the cap.
- A small amount of salt will remain in your child's hair until it is washed.
- Your child may feel some discomfort when talking about feelings and behaviours.

We will discuss these *potential* risks with your child during the consent procedure and check in to ensure their continued consent. You or your child may speak with the MMA group leaders, Integra therapist, or research leads if they require further clinical support.

Confidentiality: If you decide to participate, your information will be kept confidential and will only be reviewed by those directly involved in the research. No names or identifying information will be associated with data. All EEG data for this study will be encrypted with a password and securely stored at Ryerson University. All clinical data (e.g., questionnaires, structured interview notes) will be stored at Integra. All data for this study will be encrypted with a password and securely stored at either Integra or Ryerson University. Any research reports that result from this study will be presented in a group format, with all identifying information of participants removed.
The only exception to confidentiality is if information is disclosed that suggests that a child is at risk of harm or at risk for harming someone else. In this case, we have a duty to contact the local Children's Aid Society.

Voluntary Nature of Participation: Participation in this research is voluntary. If you decide not to participate, it will not impact on relations with or provision of services that you receive at Integra or Ryerson University. You may also decide at any time to withdraw your permission.

Benefits of the Study: We believe that this research will make an important contribution to our knowledge about how to meet the needs of youth with learning disabilities who struggle with behaviour problems, anxiety, and mood issues. This research will help us understand if participation in MMA is related with brain-based changes in emotion regulation, information that will help us in understanding how MMA helps youth. You may not receive any direct benefits from participating in the research. Upon completion of the study, a summary of the research findings will be made available to you and will be posted on the Integra website.

Questions about the Study: If you have any questions, or if you would like additional information, please ask now or feel free to contact:

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If you have questions regarding your rights as a human subject and participant in this study, you may contact the Ryerson University Research Ethics Board for information.

Research Ethics Board
c/o Office of the Vice President, Research and Innovation, Ryerson University
350 Victoria St., Toronto, ON, M5B 2K3, 416 979-5042

Consent to Participate in Research Study:

Name of Youth who has consent to participate in study:______________________________

Name of Parent/Guardian: ______________________ Date: __________________________

Signature of Parent/Guardian: ____

Signature of Investigator: _________________________ Date: _________________________

Your signature indicates that you have read the information in this agreement and have had a chance to ask any questions you have about the study. Your signature also indicates that you agree to be in the study and have been told that you can change your mind and withdraw your consent to participate at any time. By signing this agreement you are not giving up any of your legal rights. You have been given a copy of this agreement.

Appendix B: RESEARCH STUDY CONSENT AGREEMENT MMA: YOUTH CONSENT

Research Study Consent Agreement
MMA – Youth Consent

Title of Research Project: Enhancing Emotion Regulation in Youth with Self-Regulation Disorders Through Integra Mindfulness Martial Arts

We would like to invite you to participate in a research study that will help us better understand the benefits of Integra Mindfulness Martial Arts (MMA) for youth who struggle with challenges with their behaviour, anxiety, or mood. This study is being conducted for Integra by Dr. Karen Milligan, Assistant Professor in the Department of Psychology at Ryerson University.
Before you give consent, it is important to read the following information and to ask questions to ensure that you understand what you will be asked to do.

Purpose of the Study: Integra is dedicated to developing and evaluating treatment for children and youth with learning disabilities and mental health issues. MMA is one of the programs that we have developed. Our previous research has shown that MMA results in positive gains for youth in terms of behaviour, anxiety, flexibility, and impulse control. We are interested in understanding more about how MMA impacts youth, particularly in terms of emotion regulation. More specifically, we will be examining if there are brain-based changes in emotion regulation that may support youth in making positive mental health gains.

Description of the Study: Participation will involve the following:
Youth
You will be invited to attend a session (approximately 2.5 to 3 hours) 3 times during the MMA program and at 3 month follow-up. We will collect information on the electrical activity in your brain using electroencephalography (EEG). This will help us understand how brainwaves remain stable over time and relate to emotion and behaviour improvements youth make in MMA. To record brain activity, a lycra stretch cap (similar to a bathing cap) will be placed over your head. The brain sends out tiny amounts of electricity at all times, and the sensors in the cap pick up these electric signals when they reach your skin. The sensors rest on your scalp and record what's going on under the surface. A small amount of electrogel is also placed in each sensor in order to make a connection between the sensor and surface of the scalp. You can see this cap before deciding whether to participate or not. It takes about 5-10 minutes to fit and apply the cap. The cap is 100% safe, and there is no possibility of electricity or any other substance (except mild dampness) passing from the net to you. You will complete 5 short computer tasks in concert with the EEG. This will include tasks that examine changes in attention, impulse control, and psychological flexibility. You will also be asked to complete an interview about your emotions and behaviour.

Parents
Parents will be asked to complete an interview about your behaviour and emotions at the beginning of the study. They will also be asked to complete 2 questionnaires (10 minutes) four times during MMA either online or paper (your choice). For example, we will ask you to rate how true specific behaviour and emotion statements are about you. For example:

- Considerate of other people's feelings
- Loses temper often

Integra File Review
As part of the study, we would like to collect information about your learning disability and mental health. As such, we will ask you if you would consent for us to access the most recent psychoeducational assessment you completed and any parent or youth behaviour questionnaires completed at Integra (e.g., Intake forms, Strength and Difficulties Questionnaire). We would also like to access data collected as part of MMA (e.g., attendance records, homework). We will review these records onsite at Integra and no identifying information will be taken off-site.

Incentives to Participate: You will receive $25 at the end of each research testing session to cover costs associated with travel and time. Your will also receive community service hours for the time in the study (approximately 12 hours). If you decide to discontinue the study or do not attend a testing session, you will only be paid for the testing sessions you attend.

What is Experimental in this Study? All of the tasks and questionnaires used in this study have been used in previous research with children and youth.

Risks or Discomforts: There is minimal risk associated with participation in the study. *While this research study is separate and distinct from the MMA treatment that is being administered by Integra. Ryerson assumes no responsibility for risks involved in participation in the MMA treatment.*

The following minimal risks may be experienced as part of participation in the research study.

- The EEG cap can become a little uncomfortable. If you feel the discomfort level is too high, we will remove the cap immediately upon your request.
- Your hair will be messy as a result of wearing the cap.
- A small amount of salt will remain in your hair until it is washed.
- You may feel some discomfort when talking about feelings and behaviours.

We will discuss these *potential* risks with you during the consent procedure and check in to ensure their continued consent. You may speak with the MMA group leaders, Integra therapist, or research leads if you require further clinical support.

Confidentiality: If you decide to participate, your information will be kept confidential and will only be reviewed by those directly involved in the research. No names or identifying information will be associated with data. All EEG data for this study will be encrypted with a password and securely stored at Ryerson University. All clinical data (e.g., questionnaires, structured interview notes) will be stored at Integra. All data for this study will be encrypted with a password and securely stored at either Integra or Ryerson University. Any research reports that result from this study will be presented in a group format, with all identifying information of participants removed.
The only exception to confidentiality is if information is disclosed that suggests that a child is at risk of harm or at risk for harming someone else. In this case, we have a duty to contact the local Children's Aid Society.

Voluntary Nature of Participation: Participation in this research is voluntary. If you decide not to participate, it will not impact on relations with or provision of services that you receive at Integra or Ryerson University. You may also decide at any time to withdraw your permission.

Benefits of the Study: We believe that this research will make an important contribution to our knowledge about how to meet the needs of youth with learning disabilities who struggle with behaviour problems, anxiety, and mood issues. This research will help us understand if participation in MMA is related with brain-based changes in emotion regulation, information that will help us in understanding how MMA helps youth. You may not receive any direct benefits from participating in the research. Upon completion of the study, a summary of the research findings will be made available to you and will be posted on the Integra website.

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Signature of Youth: ____

Signature of Investigator: __________________________ Date: _________________________

Appendix C: RESEARCH STUDY CONSENT AGREEMENT MMA: PARENT CONSENT (Wait List)

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MMA – Parent Consent (Wait List)

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Description of the Study: Participation will involve the following:
Youth
A session (approximately 2.5 to 3 hours) will be 2 times during the length of the MMA program (20 weeks apart). We will collect information on the electrical activity in your child's brain using electroencephalography (EEG). This will help us understand how brainwaves remain stable over time and relate to emotion and behaviour improvements youth make in MMA. To record brain activity, a lycra stretch cap (similar to a bathing cap) will be placed over your child's head. The brain sends out tiny amounts of electricity at all times, and the sensors in the cap pick up these electric signals when they reach your child's skin. The sensors rest on your child's scalp and record what's going on under the surface. A small amount of electrogel is also placed in each sensor in order to make a connection between the sensor and surface of the scalp. Your child can see this cap before deciding whether to participate or not. It takes about 5-10 minutes to fit and apply the cap. The cap is 100% safe, and there is no possibility of electricity or any other substance (except mild dampness) passing from the net to your child. Youth will complete 5 short computer tasks in concert with the EEG. This will include tasks that examine changes in

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Integra File Review
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Incentives to Participate: Your child will receive $25 at the end of each research testing session to cover costs associated with travel and time. If your child decides to discontinue the study or does not attend a testing session, they will only be paid for the testing sessions they attend.

What is Experimental in this Study? All of the tasks and questionnaires used in this study have been used in previous research with children and youth.

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Consent to Participate in Research Study:

Name of Youth who has consent to participate in study:______________________________

Name of Parent/Guardian: ______________________ Date: __________________________

Signature of Parent/Guardian: ____

Signature of Investigator: _________________________ Date: _________________________

Appendix D: RESEARCH STUDY CONSENT AGREEMENT MMA: YOUTH CONSENT (Wait List)

Research Study Consent Agreement
MMA – Youth Consent (Wait List)

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Description of the Study: Participation will involve the following:
Youth
You will be invited to attend a session (approximately 2.5 to 3 hours) 2 times during the length of the MMA program (20 weeks apart). We will collect information on the electrical activity in your brain using electroencephalography (EEG). This will help us understand how brainwaves remain stable over time and relate to emotion and behaviour improvements youth make in MMA. To record brain activity, a lycra stretch cap (similar to a bathing cap)" will be placed over your head. The brain sends out tiny amounts of electricity at all times, and the sensors in the cap pick up these electric signals when they reach your skin. The sensors rest on your scalp and record what's going on under the surface. A small amount of electrogel is also placed in each sensor in order to make a connection between the sensor and surface of the scalp. You can see this cap before deciding whether to participate or not. It takes about 5-10 minutes to fit and apply the cap. The cap is 100% safe, and there is no possibility of electricity or any other substance (except mild dampness) passing from the net to you. You will complete 5 short computer tasks in concert with the EEG. This will include tasks that examine changes in attention, impulse

control, and psychological flexibility. You will also be asked to complete an interview about your emotions and behaviour.


Parents
Parents will be asked to complete an interview about your behaviour and emotions at the beginning of the study. They will also be asked to complete 2 questionnaires (10 minutes) 2 times either online or on paper (your choice). For example, we will ask you to rate how true specific behaviour and emotion statements are about you. For example:

- o Considerate of other people's feelings
- o Loses temper often

Integra File Review
As part of the study, we would like to collect information about your learning disability and mental health. As such, we will ask you if you would consent for us to access the most recent psychoeducational assessment you completed and any parent or youth behaviour questionnaires completed at Integra (e.g., Intake forms, Strength and Difficulties Questionnaire). We would also like to access data collected as part of MMA (e.g., attendance records, homework). We will review these records onsite at Integra and no identifying information will be taken off-site.

Incentives to Participate: You will receive $25 at the end of each research testing session to cover costs associated with travel and time. Your will also receive community service hours for the time in the study (approximately 6 hours). If you decide to discontinue the study or do not attend a testing session, you will only be paid for the testing sessions you attend.

What is Experimental in this Study? All of the tasks and questionnaires used in this study have been used in previous research with children and youth.

Risks or Discomforts: There is minimal risk associated with participation in the study. *While this research study is separate and distinct from the MMA treatment that is being administered by Integra. Ryerson assumes no responsibility for risks involved in participation in the MMA treatment.*

The following minimal risks may be experienced as part of participation in the research study.

- o The EEG cap can become a little uncomfortable. If you feel the discomfort level is too high, we will remove the cap immediately upon your request.
- o Your hair will be messy as a result of wearing the cap.

- A small amount of salt will remain in your hair until it is washed.
- You may feel some discomfort when talking about feelings and behaviours.

We will discuss these *potential* risks with you during the consent procedure and check in to ensure their continued consent. You may speak with the MMA group leaders, Integra therapist, or research leads if you require further clinical support.

Confidentiality: If you decide to participate, your information will be kept confidential and will only be reviewed by those directly involved in the research. No names or identifying information will be associated with data. All EEG data for this study will be encrypted with a password and securely stored at Ryerson University. All clinical data (e.g., questionnaires, structured interview notes) will be stored at Integra. All data for this study will be encrypted with a password and securely stored at either Integra or Ryerson University. Any research reports that result from this study will be presented in a group format, with all identifying information of participants removed.
The only exception to confidentiality is if information is disclosed that suggests that a child is at risk of harm or at risk for harming someone else. In this case, we have a duty to contact the local Children's Aid Society.

Voluntary Nature of Participation: Participation in this research is voluntary. If you decide not to participate, it will not impact on relations with or provision of services that you receive at Integra or Ryerson University. You may also decide at any time to withdraw your permission.

Benefits of the Study: We believe that this research will make an important contribution to our knowledge about how to meet the needs of youth with learning disabilities who struggle with behaviour problems, anxiety, and mood issues. This research will help us understand if participation in MMA is related with brain-based changes in emotion regulation, information that will help us in understanding how MMA helps youth. You may not receive any direct benefits from participating in the research. Upon completion of the study, a summary of the research findings will be made available to you and will be posted on the Integra website.

Questions about the Study: If you have any questions, or if you would like additional information, please ask now or feel free to contact:

Dr. Karen Milligan, C. Psych.
Assistant Professor, Ryerson University
416 486-8055 x232
karen.milligan@psych.ryerson.ca

Trish McKeough, MSW, RSW
MMA Supervisor
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Clinical Director, Integra
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If you have questions regarding your rights as a human subject and participant in this study, you may contact the Ryerson University Research Ethics Board for information.

Research Ethics Board

c/o Office of the Vice President, Research and Innovation, Ryerson University
350 Victoria St., Toronto, ON, M5B 2K3, 416 979-5042

Your signature indicates that you have read the information in this agreement and have had a chance to ask any questions you have about the study. Your signature also indicates that you agree to be in the study and have been told that you can change your mind and withdraw your consent to participate at any time. By signing this agreement you are not giving up any of your legal rights. You have been given a copy of this agreement.

Consent to Participate in Research Study:

Name of Youth who has consent to participate in study:______________________________

Name of Parent/Guardian: ______________________ Date: __________________________

Signature of Youth: ____

Signature of Investigator: _________________________ Date: ________________________

Appendix E: CLIENT INFORMATION FORM

Client Information Form

Name: ___________________________ Participant #:_______

Address:__________________________________

____

____

Home Phone: ___________________________________

Cell Phone: ___________________________________

Parent Email Address: ____

Youth Email Address: ____

Date of Birth: _____________________________

Grade:___________________________________

Ethnicity: ________________________________

Level of household income: (Please circle)

Less than $25,000

25,000-50,000

50,000-$75,000

$75,000-$100,000

$100,000- $150,000

more than $200,000

Is your child currently taking any medication? Y N

Please turn over.

If yes, what kind of medication.______________________________________

Is your child right or left handed? ____________________________________

Does your child have any diagnosed or identified learning disabilities or mental health issues? Please describe.

____

____

Is your child currently participating or in the past participated in any individual, group, or family interventions related to mental health? Please list and specify if current or past.

____

____

In addition to MMA, is your child currently participating or in the past participated in any sport or physical fitness activities? If yes, please list what activities and if current or past.

Daytime Emergency Contact:

Name: _________________________________ Phone: _______________________

Appendix F: CONSENT TO DISCLOSE PERSONAL HEALTH INFORMATION – INTEGRA TO CHILD SELF-REGULATION LAB, RYERSON UNIVERSITY

Consent to Disclose Personal Health Information

Pursuant to the Personal Health Information Protection Act, 2004 (PHIPA)

I, ____________________________, authorize **Integra**

(Print your name) ***(Print name of health information custodian)***

to disclose **the personal health information of**

____

(Name of person for whom you are the substitute decision-maker*)

consisting of: Psychoeducational Assessment Report/ Assessment Scores, questionnaires completed as part of Intake or service at Integra, data collected as part of MMA (attendance records, homework completion records

to **Child Self-Regulation Lab, Ryerson University (under the care of Dr. Karen Milligan)**

I understand the purpose for disclosing this personal health information to the person noted above. I understand that I can refuse to sign this consent form.

My Name:________________________ Address:____________________________________

Home Tel.:________________________ Work Tel.: ______________________________

Signature:_________________________Date:_______________________________________

Witness Name:_____________________Address:____________________________________

Home Tel.:________________________ Work Tel.:_____________________________

Signature:_________________________Date:_______________________________________

***Please note: A substitute decision-maker is a person authorized under PHIPA to consent, on behalf of an individual, to disclose personal health information about the individual.**

Appendix G: CONSENT TO DISCLOSE PERSONAL HEALTH INFORMATION – CHILD SELF-REGULATION LAB, RYERSON UNIVERSITY TO INTEGRA

Consent to Disclose Personal Health Information

Pursuant to the Personal Health Information Protection Act, 2004 (PHIPA)

I, **____________________________,** authorize **Child Self-Regulation Lab, Ryerson**
(Print your name)

University (under the care of Dr. Karen Milligan) to disclose **the personal health information of**

____

(Name of person for whom you are the substitute decision-maker*)

consisting of: Participation status, progress in research study, any behaviours or events that may require clinical follow-up by Integra staff to support child/family.

to **Integra**

I understand the purpose for disclosing this personal health information to the person noted above. I understand that I can refuse to sign this consent form.

My Name:________________________ Address:____________________________________

Home Tel.:________________________ Work Tel.: ______________________________

Signature:_________________________Date:____

Witness Name:_____________________Address:____________________________________

Home Tel.:________________________ Work Tel.:________________________ ______

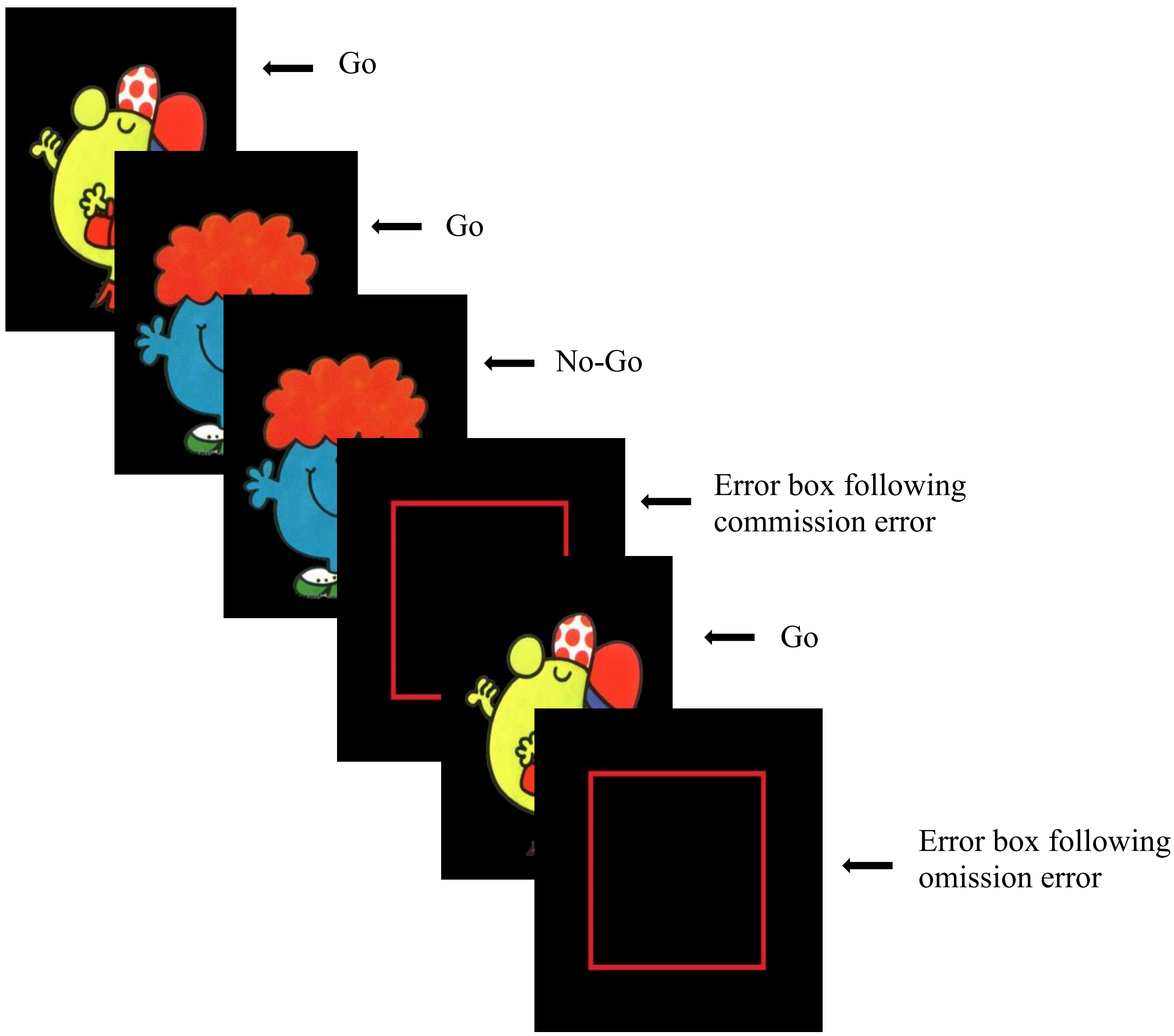
Signature:_________________________Date:____

***Please note: A substitute decision-maker is a person authorized under PHIPA to consent, on behalf of an individual, to disclose personal health information about the individual.**

Appendix H: AUDIO ODDBALL TASK SCRIPT

Initial Direction:	In this task you are going to hear high and low pitched sounds presented randomly to the left or right. The high tone is the target tone. In some blocks of trials you will be asked to pay attention to sounds on the left only and ignore all those on the right. In other blocks you will be asked to pay attention to sounds on the right and ignore those on the left. Your job is to press button 1 only to the high-pitched target tone and only when it sounds on the side you are being told to pay attention to.
Example:	Here is one example of the target tone.
	Here are a few sample sounds. Try and listen for those that are high pitched and those that are lower pitched. Remember, those that are high pitched are going to be the targets.
First Block Example:	For this first block please pay attention to sounds on the LEFT side only. Press the button to target (i.e., higher pitched) tones heard on the LEFT side. Ignore all sounds in the right side.
Subsequent Blocks Example:	After the break please pay attention to sounds in your RIGHT ear only. Press the button for target tones heard in the RIGHT ear.

Appendix I: SAMPLE GO/NO-GO TASK SEQUENCE



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