Effects of Sensory Processing Patterns on Inhibitory Control as a Function of ADHD-traits and Trait Anxiety

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Abstract

Anxiety and ADHD (traits) have been shown to co-occur in both clinical and non-clinical populations. In addition, both anxiety and ADHD are independently associated with atypical sensory processing. However, there has been no previous research investigating their combined effects on cognitive functions. It is important to identify the nature of their interactions, because often the impact of multiple challenges in affective, social, and cognitive domains can be different from the impact of each individual condition. The dimensional models of mental disorders regard psychopathologies as continuous, interdependent conditions with symptoms existing as traits along a continuum in the population, rather than discrete diagnostic categories. Following this framework, the overarching goal of this event-related potential study is to investigate how individual differences in sensory processing patterns (SPPs), ADHD-traits and trait anxiety influence inhibitory control in 77 (final sample 60, ages 18-26) female and male non-clinical emerging-adults. It was expected that the effect of the SPPs on inhibitory control would depend on the level of ADHD-traits which are moderated by the level of trait anxiety. Two SPPs, low registration (LR) and sensory sensitivity (SS), ADHD-traits (inattention, impulsivity, hyperactivity) and trait anxiety were measured using self-report questionnaires. Inhibitory control was operationalized as the maximum peak amplitude of N2, a neurophysiological response frequently associated with inhibition paradigms. In this study, N2 response was elicited during a 22-minute computerized distractor Continuous Performance Task (d-AX-CPT) with three inhibitory conditions (Go Distractor, NoGo Distractor, NoGo No Distractor). The research hypotheses were tested in moderated moderation models separately for LR and SS as focal predictors, N2 amplitude as the outcome, and ADHD-traits and trait anxiety as primary and secondary moderators, respectively. The results revealed that the levels of

impulsivity, but not hyperactivity and inattention, and trait anxiety together moderated the effects of SPPs on N2 amplitude in Go Distractor and NoGo Distractor Conditions. In general, the findings of this study (1) highlight the importance of understanding the complex relationships among comorbid patterns that are frequently observed in diagnostic groups, (2) add new information to the existing literature on the relationship between SPPs, ADHD and anxiety using a dimensional framework.

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Overview

In 2009, the National Institute of Mental Health (NIMH) initiated a dynamic and multidimensional research framework, Research Domain Criteria (RDoC), to better understand the fundamental processes in affective, cognitive, social, arousal/regulatory and sensorimotor systems underlying mental health and illness (Hengartner & Lehmann, 2017). RDoC framework uses a dimensional approach in studying the neurodevelopmental and continuous nature of mental disorders and it has strong potential to address the complex pattern of comorbidities (Hengartner & Lehmann, 2017). Recently several researchers have proposed to add a *sensory processing* dimension to the RDoC matrix as converging evidence has shown the significant role of sensory processing challenges in the etiology and the maintenance of several disorders including anxiety and ADHD (Harrison et al., 2019). Following this emerging and transformative dimensional trend in mental health research, this thesis conceptualized sensory processing as a transdiagnostic mechanism and vulnerability factor that can negatively impact cognitive outcomes, especially when it interacts with other vulnerability factors, such as heightened anxiety and ADHD-traits. In addition, I adopted a dimensional framework as these sensory, affective, and behavioural constructs were studied as continuous traits rather than discrete diagnostic categories.

The manner that individuals differ in perceiving and responding to sensory stimuli is referred to sensory processing patterns (SPPs) by Dunn (1997). Dunn proposed four sensory patterns (sensory sensitivity, low registration, sensory avoidance and sensation seeking) along two-dimensions: one-dimension indexes a person's neurological threshold for perceiving stimuli (low to high thresholds) and the second dimension depicts the behavioural strategies used when the individual responds to these stimuli (passive to active strategies). Of these four patterns, two

patterns are used in this study. Sensory sensitivity (SS) is defined as a low threshold/passive strategy pattern. Individuals with high SS tend to perceive stimuli at lower intensities. These individuals are more aware and distracted by stimuli that generally do not trigger discomfort in other people (Brown & Dunn, 2002). On the other hand, low registration (LR) is defined as a high threshold/passive strategy pattern. People who are dominated by this sensory pattern are generally unaware of the stimuli (or surroundings) and take longer to react to the stimuli (Brown & Dunn, 2002). On a behavioral continuum both SS and LR are associated with passive response strategies, meaning that the individual with SS and/or LR does not actively try to manipulate the situation. For example, a person with high SS may be bothered by bright lights but does not attempt to dim the lights. Both SS and LR have been associated with internalizing (Engel-Yeger et al., 2016; Engel-Yeger & Dunn, 2011; Liss et al., 2005; McMahon et al., 2019; Xiao et al., 2010; Engel-Yeger et al., 2016) and externalizing difficulties (Clince et al., 2016; Little et al., 2018; Panagiotidi et al., 2018). Due to this relationship, in this study, SS and LR are conceptualized as transdiagnostic risk factors that may elevate the risk of adverse cognitive outcomes (for example, excessive or insufficient inhibitory control) in the presence of externalizing (ADHD-traits) and internalizing (trait anxiety) conditions.

ADHD and anxiety are often comorbid, with estimates ranging from 25% (D'Agati et al., 2019) to 40% (Tannock, 2009). Co-occurring anxiety disorders alter the presentation, the prognosis, and the treatment of ADHD (D'Agati et al., 2019). Although anxiety and ADHD independently influence affective and cognitive functioning, the deficits may be exacerbated if an individual has both. For example, co-morbid anxiety in individuals with ADHD has been related to greater deficits in self-regulation of emotion and self-organization/problem solving compared to ADHD-only and anxiety-only individuals (Jarrett, 2016). Greater social (Mikami et

al., 2011) and academic impairments (Jensen et al., 2001) are more frequently reported in individuals presenting both anxiety and ADHD. Klymkiw and colleagues (2017) suggested that the observed increase in impairments in social-cognitive and affective domains in anxiety and ADHD comorbidity may be due to difficulties in attentional and impulse control. Anxiety and ADHD comorbidity has been linked to extreme patterns of sensory processing (Ghanizadeh, 2011). For example, ADHD children with sensory over-responsivity (SOR; similar to SS) were more anxious than ADHD-only children (Reynolds & Lane, 2009).

Inhibitory control is an aspect of cognitive control responsible for the suppression of distracting stimuli (Tiego et al., 2018). Inhibitory control can be divided into *response inhibition*, the ability to supress a prepotent motor response, and *attentional/cognitive inhibition*, the ability to resist internal and external distractor stimuli (Tiego et al., 2018). Both anxiety and ADHD have been associated with difficulties in inhibitory control (Berggren & Derakshan, 2013; Connors et al., 2003; Crosbie et al., 2013; Epstein et al., 2003; Eysenck et al., 2007; Xia et al., 2020). Studies investigating response inhibition in standard Go/NoGo tasks suggest that individuals with anxiety compared to individuals without anxiety show increased response inhibition as they make fewer commission errors in the NoGo condition, where inhibition of a prepotent response is required (Grillon et al., 2017). On the other hand, individuals with ADHD compared to the ones without ADHD make more commission errors and have slower or more variable reaction times during tasks that require sustained attention and inhibition, such as the Continuous Performance Task (CPT) (Corkum & Siegal, 1993; Epstein et al., 2003; Overtoom et al., 1998). Similar to the results with clinical groups, in community samples greater ADHD-traits were related to worse response inhibition, slower reaction times, and greater response variability in inhibitory tasks (Crosbie et al., 2013). Overall, behavioural studies suggest increased response

inhibition in anxious individuals but reduced response inhibition in individuals with ADHD (Crosbie et al., 2013; Corkum & Siegal, 1993; Epstein et al., 2003; Grillon et al., 2017; Overtoom et al., 1998). Cognitive inhibition has been found to be negatively affected in anxious individuals due to an increased role in the stimulus driven attentional system, especially to perceived threat (Cisler & Koster, 2010; Eysenck et al., 2007). Cognitive inhibition does not seem to be affected in individuals with ADHD (Carr et al., 2006; Engelhardt et al., 2008; Gaultney et al., 1999), unlike response inhibition.

In addition to behavioural measures, taking an event-related potential (ERP) approach provides a window into has been employed to investigate the neural correlates of inhibition. The N2, a negative-going component that is elicited around 200-400 ms after stimulus presentation, has been used to index a neurophysiological response elicited in tasks requiring inhibition and is recorded in the frontocentral scalp electrodes (Klymkiw et al., 2017). In general, the N2 is larger in amplitude when participants successfully inhibit their responses to a rare NoGo stimulus (Falkenstein et al., 1999), but this response can be modulated by behavioural and affective factors. ERP studies examining youth with ADHD have shown that the individuals with ADHD had significantly smaller N2 amplitudes to NoGo stimuli compared to youth without ADHD (Dimoska et al., 2003; Johnstone et al., 2009; Liotti et al., 2010). Overall, ERP research has shown that ADHD may be associated with altered neurophysiological responses to inhibitory control demands as indicated by smaller N2 amplitudes and longer latencies. However, contrary to these findings, Fisher and colleagues (2011) found that the adults diagnosed with ADHD and those without ADHD did not differ in NoGo N2 amplitude, although the ADHD group had longer N2 latencies.

In terms of anxiety the results have been controversial. For example, although some studies have shown larger NoGo N2 amplitudes (Hum et al., 2013; Righi et al., 2009), other studies revealed either no difference (Yang & Li, 2014) or even reported smaller N2 amplitudes (Xia et al., 2020) during tasks requiring inhibition in clinically anxious or high trait anxious participants compared to non-anxious controls. Hum and colleagues (2013) suggested that anxious children showed greater medial-frontal activity regardless of task demands and response accuracy. This activity may be the basis for the hypervigilant regulatory style in anxious individuals. On the other hand, Xia and colleagues (2020) suggested that response inhibition deficits are the result of abnormal premotor inhibitory control and inefficient evaluation and monitoring. Overall, the results of behavioural studies suggest that anxiety is related to augmented response inhibition, whereas its neurophysiological correlates are not as clear.

At the neurological level, sensation and cognition are intrinsically connected through several cortical and subcortical networks, which suggests that extremes in one system may impact the other (Mesulam, 1998, 2008). There have been several clinical and empirical studies on the effects of comorbid ADHD and anxiety, anxiety and sensory processing, and ADHD and sensory processing, but the possible effects of these three conditions together on cognitive functions have yet to be investigated. Due to this lack of research considering the impact of all three conditions simultaneously, this thesis was designed to capture the complexity of the possible effects of co-existing ADHD-traits (inattention, hyperactivity and impulsivity) and trait anxiety in the relationship between two SPPs (LR and SS). The results suggest that there is a complex relationship among extreme SPPs, impulsivity and trait anxiety, which affects inhibitory control. In addition, this study adopted the dimensional framework because: (a) the characteristics of ADHD and anxiety were studied as continuous traits in a non-clinical sample;

and (b) the nature of the relationships among these traits were analysed in models that accounted for their interdependencies.

Two non-directional hypotheses, one for each SPP were generated. Overall, it was expected that the effect of the SPPs (LR and SS) on inhibitory control would depend on the level of ADHD-traits that would itself be moderated by the level of trait anxiety. Specifically, a three-way interaction between SPPs, trait anxiety, and ADHD-traits was hypothesized for each model. These hypotheses were tested in moderated moderation models separately for LR and SS as focal predictors, N2 amplitude as the outcome, ADHD-traits and trait anxiety as primary and secondary moderators, respectively. A total of 77 male and female university students, ages 18-26, participated in this study for research credits. Due to some unusable data, the final sample consisted of 60 participants. SPPs were measured using the Adolescent Adult Sensory Profiles (AASP, Brown & Dunn, 2002), trait anxiety was measured by the State Trait Anxiety Inventory (STAI, Spielberger et al., 1983) and the ADHD-traits were measured by Conners' Adult ADHD Rating Scales (CAARS, Conners et al., 1999). The participants were presented a variant of a Continuous Performance Task named the (distractor) d-AX-CPT with three prominent distractor conditions while the continuous EEGs were recorded from 128-channel system simultaneously (see Methods for the details). The d-AX-CPT consisted of letters of the alphabet and participants were required to respond to the letter X, only when it was preceded by the letter A. Two main conditions of the d-AX-CPT[1] relevant to this study were A-X letter sequences (Go conditions) and A-not X letter sequences (NoGo conditions). Distractor stimuli in the form of simple line drawings were also presented 50% of the time during both Go and the NoGo conditions in order to be able to study cognitive inhibition and to increase task difficulty. Inhibitory control was

[1] These conditions were defined in detail in Chapter 2 Methods on page 34

operationalized as the maximum peak amplitude of N2, a neurophysiological response frequently associated with inhibition and was defined within 200-300 ms window post stimulus during Go-Distractor, NoGo Distractor and NoGo No Distractor conditions.

Findings showed that in both LR and SS models, hypothesized three-way interactions among the focal and moderator predictors were confirmed only in Distractor conditions and only when impulsivity was the primary moderator, inattention or hyperactivity were not significant moderators. In other words, impulsivity moderated the effect of SPPs on N2 amplitude, but this effect was also dependent on the level of trait anxiety. In general, the results suggest that the complex comorbidity patterns are important because their co-occurrence tended to change the outcome variable, specifically inhibitory control. These results should be evaluated as preliminary and require replication especially in individuals diagnosed with ADHD and anxiety. This study makes valuable contributions to the understanding of the multidimensional and dynamic nature of comorbid ADHD and anxiety, and therefore has important implications in the area of mental disorders.

Low Registration and Sensory Sensitivity were the only 2 sensory processing patterns used in the analysis. Both traits have been related to ADHD and anxiety consistently (Clince et al., 2016; Engel-Yeger et al., 2011; Engel-Yeger & Dunn, 2016; Panagiotidi et al., 2018) and share a passive profile. Due to the complexity of these analyses using only two sensory processing patterns simplifies the analysis. In addition, only the 3 inhibitory conditions are examined and will be discussed in detail. The control condition (Go No Distractor) will not be interpreted and discussed as it is not indexing inhibitory control. However, the implications of finding a 3-way interaction in Go No Distractor Condition will be mentioned.

Literature Review

Sensation to Cognition

The human brain processes an overwhelming amount of sensory information at any given time (Bernays & Wcislo, 1994). Sensory information is received by the primary sensory areas that send information to unimodal and transmodal processing sectors of the cortex (Mesulam, 1998). The upstream sections of the unimodal association areas encode basic features of sensation (e.g., colour) and more complex contents of the sensory experience are encoded within downstream sectors (e.g., faces) of unimodal areas (Mesulam, 1998). This information is projected to heteromodal and transmodal areas (e.g., paralimbic and limbic cortices). However, information does not flow in just one direction, as higher-level processing areas can exert top-down influence (feedback) to lower areas. The ability for an individual to experience multiple cognitive and behavioural outcomes from a single sensory event is due to the reciprocal connections between different parts of the brain that underlie several levels of parallel and serial processing of sensory information (Mesulam, 1998). Therefore, sensation and cognition are intrinsically connected through several cortical and subcortical networks and are inevitably reflected in emotions and behaviour.

As sensation is a critical component in the cognitive and affective domain (Bernays & Wcilso, 1994; Mesulam, 1998, 2008; Pessoa et al., 2003), several sensory processing models have been proposed. Some models make sensory processing extremes a diagnosable disorder (see Sensory Integration model, Miller et al., 2007), whereas in other models the focus is on how individuals respond to environmental cues, such as the Differential Susceptibility model proposed by Belsky and Pluess (2009).

In the following section, Dunn's sensory processing model that has been frequently used, especially in the area of occupational therapy, is explained in detail. Dunn's model and the assessment instrument developed from this model is used in this thesis.

Dunn's Sensory Processing Model: Individual Differences in Sensory Processing

Individual variations in sensory processing (ie., why some individuals are more or less responsive to sensory information) can be explained at different levels of processing in the nervous system. At a very basic neuronal level, habituation and sensitization, two key adaptive neurophysiological mechanisms play an important role sensory processing (Bernays & Wcislo, 1994). Blumstein (2016) defined habituation "as a process that leads to decreased responsiveness to a stimulus with repeated presentation[..] it makes less likely that individuals will respond to harmless stimuli" and sensitization "is increased responsiveness to a stimulus with repeated presentation" (p. 255). These two basic processes have been important in defining different sensory processing patterns in Dunn's model.

Dunn (1997) introduced a model to explain SPPs and developed the Sensory Profiles, an assessment instrument that allows the examination of sensory modulation difficulties in children, adolescents and adults (Brown & Dunn, 2002). In her model she uses a dimensional/continuous approach as opposed to looking at only extremes of sensory processing. Therefore, Dunn's model and the questionnaire she developed fit in well with the dimensional framework adopted in this study.

Dunn explains sensory processing differences at the level of habituation and sensitization (neurological thresholds) and at the behavioural level (i.e. behavioural strategies). According to Dunn (1997), habituation and sensitization in the CNS underlie different patterns of sensory processing. The pattern of interchange between habituation and sensitization is referred to as

neurological thresholds. Neurological thresholds range on a continuum from low to high (Dunn, 1997). For example, individuals with high thresholds are slower to detect the stimuli and are expected to habituate to repeated stimuli faster. On the other hand, individuals with low thresholds are quick to detect the stimuli and expected to show slow habituation (Brown et al., 2001; Little et al., 2018; Metz et al., 2019). The second component of Dunn's model is the *behavioural strategies*. Behavioural strategies are individuals' response patterns in relation to their neurological thresholds and range from passive to active strategies (Dunn, 1997; Metz et al., 2019). Individuals who adopt an active strategy are reactive to stimuli and may try to change their environment to better suit their neurological thresholds (Little et al., 2018; Metz et al., 2019). On the other hand, individuals who adopt a passive strategy may not act to change their environment (Metz et al., 2019). According to Dunn, both neurological thresholds and behavioural strategies influence social, cognitive and sensorimotor development (Dunn, 1997).

Dunn defines four SPPs: low registration, sensory sensitivity, sensation seeking and sensory avoidance (Brown & Dunn, 2002). As in this study only two SPPs were analysed this review covers these SPPs, low registration (LR) and sensory sensitivity (SS). LR is defined as high neurological threshold and passive strategy, whereas SS is a low neurological threshold and passive strategy. Sensation Seeking is a high neurological threshold and active strategy, whereas Sensory Avoidance is low neurological threshold and active strategy (Dunn, 1997). These different sensory processing patterns (SPP) depend on patterns of habituation and sensitization (See Table 1). For example, strong initial responses to sensory input and slow habituation are related to low neurological thresholds with passive responses (Brown et al., 2001). Conversely, weak initial responses to sensory information and fast habituation are related to high

neurological thresholds with passive responses. Individuals with high neurological thresholds and active response strategies are associated with average habituation (Brown et al., 2001).

Table 1

Dunn's Model of Sensory Processing (Dunn, 1997)

	Behavioural Response	
Neurological thresholds	Passive	Active
High Threshold (Habituation)	**Low Registration** A person who misses sensory stimuli	**Sensation Seeking** A person who enjoys exciting stimuli
Low Threshold (Sensitization)	**Sensory Sensitivity** A person who is distracted by and uncomfortable with sensation	**Sensation Avoiding** A person who limits exposure to sensory stimuli

Note: Hypothetical cases are given as examples

Each level of threshold and strategy (i.e., quadrants) represents a separate but related construct (See Table 1). Since the questionnaire is scored by quadrants, an individual could have a high score in more than one quadrant, even if they have an opposite behavioural response or neurological threshold. Therefore, each sensory processing pattern lies on a continuum, with one end meaning a person largely lacks that characteristic, the middle values meaning they are more adaptable and the other end of the continuum they are dominated by the characteristic. The characteristics that are expressed may depend on the context of the environment. A person may present different sensory patterns depending on the environment. A person may express Sensory Sensitivity or Sensation Avoiding patterns at a loud music festival, but they may also demonstrate Low Registration in a quiet library. Clinical populations have shown high scores in patterns with different neurological thresholds.

ADHD and Sensory Processing

ADHD is a neurodevelopmental disorder characterized by hyperactive behaviour, impulsivity, and inability to sustain attention (Bell, 2011). Clinically, the DSM-5 defines 3 categorically different subtypes of ADHD: inattentive, hyperactive-impulsive, and combined. Although ADHD can be diagnosed in adulthood, symptoms can be dated back before age 7 (Bell, 2011).

Research supports the link between ADHD symptomatology and sensory processing difficulties, but the direction of the causality has been controversial (Lane et al., 2010) as both hypo-arousal and hyper-arousal states were reported in individuals with ADHD (Du Rietz et al., 2019; Mayer et al., 2016; Shi et al., 2012). Dunn and Bennett (2002) examined the Sensory Profiles of children diagnosed with ADHD. Children with ADHD had higher scores in sensation seeking, emotional reactivity, inattention/distractibility and fine motor/perceptual, compared to typically developing children. Little and colleagues (2018) investigated the sensory processing patterns in children with ADHD, Autism-Spectrum Disorder (ASD) and typically developing children (TD) using Dunn's model. They found that ADHD and ASD did not differ on sensory processing patterns and but both groups showed more extreme sensory processing patterns compared to TD (Little et al., 2018). Differences in sensory processing are well-documented in ASD and are often considered to be an essential part of the disorder. This suggests that in ADHD children these sensory processing patterns are extreme. Mangeot and colleagues (2001) investigated Sensory Modulation Dysfunction (SMD) in children with ADHD. SMD is the ability to regulate and organize the degree, strength and nature of responses to sensory input in an adaptive way. SMD contains two extreme behavioural patterns: Sensation Seeking and Sensation Avoiding. To study SMD the researchers measured electrodermal reactivity to

repeated sensory stimulation and found that children with ADHD demonstrated greater sensory modulation dysfunction on both physiological and parent-report measures compared to typically developing children. Additionally, the children with ADHD also displayed more variability in sensory processing. Levels of SMD were highly correlated with measures of psychopathology on the Child Behaviour Checklist in children with ADHD (Mangeot et al, 2001).

A meta-analysis conducted by Ghanizadeh (2011) showed that sensory processing problems are more common in children with ADHD compared to typically developing children, although in this study the relationships between sensory processing difficulties and different ADHD subtypes were not analyzed. It is possible that different ADHD subtypes are related to different sensory processing difficulties. In children with ADHD, comorbid oppositional defiant disorder (ODD) and anxiety predicted more severe sensory processing problems (Ghanizadeh, 2011). Ghanizadeh (2011) suggests that there is not a lot of research in the field and suggests that the comorbidities should be considered further as some studies have shown more severe sensory processing patterns when an individual has comorbid disorders. For example, ADHD children with sensory over-responsivity (SOR; similar to SS) were more anxious than ADHD-only children (Reynolds & Lane, 2009).

In community adult samples, ADHD-traits were related to sensory processing abnormalities. Clince and colleagues (2016) found that emerging adults with ADHD reported greater sensation seeking, low registration, and sensory sensitivity compared to individuals without ADHD. Clince and colleagues (2016) investigated emerging adults with ASD and found relatively few differences between sensory processing patterns in students with ADHD and ASD. The ADHD group had significantly higher scores on average in low registration, sensory sensitivity and sensation avoiding than the general population, suggesting they show more of

these traits. These results are similar to the study done by Little and colleagues in children (Clince et al., 2016). Panagiotidi and colleagues (2018) examined ADHD traits in the general population and found a positive relationship between the number of ADHD traits and the frequency of reported sensory processing problems, including both hyper- and hyposensitivity. Additionally, the level of ADHD was related with an increased number of sensory difficulties in all modalities (Panagiotidi et al., 2018).

Anxiety and Sensory Processing

Individuals without a diagnosed anxiety disorder can also experience higher than normal levels of anxiety. Trait anxiety is a personality characteristic defined by chronic feelings of anxiety, relatively independent of situational factors (Eysenck et al., 2005). Trait anxiety is assumed to be normally distributed in the general population (Creamer et al., 1995), and accepted as a vulnerability factor in the development of anxiety and mood disorders (Raymond et al., 2017). Trait anxiety and anxiety disorders have been linked to sensory sensitivities (Engel-Yeger & Dunn, 2011; Engel-Yeger et al., 2016; Liss et al., 2005; McMahon et al., 2019; Xiao et al., 2010). For example, Xiao and colleagues (2010) found a significant relationship between anxiety disorders (e.g., generalized anxiety disorder) and sensory processing difficulties. McMahon and colleagues (2019) investigated childhood sensory processing disorder (SPD) and diagnosis of anxiety disorder in a longitudinal study. They found that the childhood SPD was significantly associated with a higher likelihood of a lifetime anxiety disorder diagnosis and this relationship was fully mediated by emotion regulation difficulties (McMahon et al., 2019). The authors argued that high SPD symptoms led to high emotion dysregulation that put individuals at risk for developing an anxiety disorder (McMahon et al., 2019). Liss and colleagues (2005) studied whether negative affect in anxiety and depression was related to high sensory processing

sensitivity, or whether the poor parenting was underlying the relationship among anxiety, depression and high sensory sensitivity. The findings showed that the sensory processing sensitivity was predicted by both anxiety and depression above and beyond parental factors, suggesting that sensory processing sensitivity is an independent risk factor in these disorders (Liss et al., 2005). Overall, the research demonstrates that anxiety and related disorders are linked to extreme sensory processing patterns.

In a study examining major affective disorders and sensory processing patterns using Dunn's model revealed that anxious and irritable affective temperament were predicted by LR (Engel-Yeger et al., 2016), whereas SS predicted depression and anxious/cyclothymic-anxious temperaments (Engel-Yeger et al., 2016). Therefore, individuals with major affective disorders, like individuals with ADHD, tend to show both hypersensitive (low neurological threshold) and hyposensitive (high neurological threshold) patterns of sensory processing. Engel-Yeger and colleagues (2016) suggest that these extreme sensitivities may be a "trait" marker for those with major affective disorders. Besides the anxiety disorders, some researchers have investigated trait anxiety in healthy populations. Engel-Yeger and Dunn (2011) found that the adults with high scores in SS, LR and sensory avoiding, demonstrated elevated trait and state anxiety (Engel-Yeger & Dunn, 2011).

A possible explanation for the link between extreme sensory processing patterns and anxiety is to have a hypervigilant-regulatory style, with attentional bias to threat-related stimuli in the model (Eysenck et al., 2007; Inzlitcht et al., 2015). Individuals with sensory hypersensitivities (SS & sensory avoiding) have physiological tendencies to process information at lower neurological thresholds with decreased habituation (Engel-Yeger et al., 2016). This pattern of responsiveness predisposes individuals to be more attentive and physiologically

reactive to possible threats in the environment and more vulnerable to anxiety (Engel-Yeger & Dunn, 2011; Liss et al., 2005). The similarity between the sensory processing profile of both anxious and hypersensitive people may help to explain why the two are related; however, it does not explain the directionality of this relationship. Overall, anxiety is typically characterized by a hypervigilant regulatory style, and has been related to the LR, SS and sensory avoiding.

In sum, converging evidence show that in both ADHD and anxiety, hyper and hypo-responsiveness have been observed. Individuals with ADHD experience hyper-responsiveness as well as hypo-responsiveness to sensory stimuli and they have difficulty modulating sensory input, suggesting that sensory difficulties could be a component of the ADHD phenotype (Panagiotidi et al., 2018). Similar trends have also been observed in anxiety. Although, the individuals with anxiety typically have hypervigilant regulatory style, which has been related to low neurological threshold, Low Registration (a high neurological sensory threshold pattern) has also been reported in anxiety (Engel-Yeger & Dunn, 2011).

Inhibitory Control

Cognitive control is necessary to achieve goal-directed thought and actions (Koechlin et al., 2003), especially when distracting stimuli are present in the environment (Corbetta & Shulman, 2002). Research has shown that inhibition is multifaceted. Nigg (2000) identified four types of effortful inhibition: interference control (interference due to resource or stimulus competition), cognitive inhibition (suppression of irrelevant information from working memory), behavioural inhibition (suppression of prepotent responses) and oculomotor inhibition (suppression of reflexive saccades). Friedman and Miyake (2004) found that interference control, behavioural inhibition and oculomotor inhibition were involved in the same underlying inhibitory functioning. Most research studying inhibition uses the constructs of response

inhibition (behavioural inhibition), and cognitive inhibition (attentional inhibition) (Tiego et al., 2018).

ADHD and Inhibitory Control

ADHD is characterized by dysregulation of cognitive control. Conners Continous Performance Task (CPT) is a neuropsychological test that has been a gold standard assessment tool in ADHD and used to measure response inhibition on NoGo trials (Conners, 2002; Conners et al., 2003; Epstein et al., 2003). Individuals with ADHD make more errors and have slower reaction times on CPT (Corkum & Siegel, 1993; Overtoom et al., 1998). A meta-analysis performed by Epstein and colleagues (2003) examined the CPT performance variables in 817 children. It was found that the children diagnosed with ADHD had more variable RTs and made more commission (NoGo trials) and omission errors (Go trials) (Epstein et al., 2003). Increased variability in RTs, measured by standard error, over time was related to most ADHD symptoms. Mean hit RT was slower for individuals with ADHD and is more related to symptoms of hyperactivity than other ADHD symptoms (Epstein et al., 2003).

Response inhibition difficulties have been related to ADHD traits in clinical and non-clinical adults. Woltering and colleagues (2013) studied inhibitory control using a Go/NoGo task in conjunction with ERPs. The results indicated that the ADHD group had lower accuracy in Go and NoGo conditions and significant reductions in NoGo P3 amplitude. Additionally, there was a trend for reduced NoGo N2 amplitude, although it was not significant. It is important to note that N2 latencies had the largest standard deviation that could suggest trial-to-trial jitter leading to attenuated ERPs, although it was not explicitly discussed in the study. Woltering and colleagues (2013) found that higher ADHD symptoms were related with smaller amplitudes, therefore; in combination with lower response accuracy this suggests poorer inhibitory control in ADHD

individuals. In a community sample, individuals with greater ADHD-trait scores had worse response inhibition, slower response times, and greater variability within Go responses on a Stop-Signal Task (Crosbie et al., 2013). Wodka and colleagues (2007) studied response inhibition in children with ADHD with 3 Go/NoGo tasks: one with high working memory demands (cognitive), one with low working memory demands (simple) and one with rewards and response costs (motivation). Children with ADHD made significantly more commission errors than typical children in all tasks. Overall, both performance and ERP responses in inhibitory tasks suggest poorer inhibitory control in non-clinical populations as well as individuals diagnosed with ADHD.

Engelhardt and colleagues (2008) examined both cognitive inhibition and working memory in adolescents and adults with ADHD. To measure working memory, a Stroop task was used and to measure cognitive inhibition via language processing, a garden path task was used. Garden path sentences include a misleading opening (called a temporary ambiguity) in which the participant is led toward one interpretation. Further information in the same sentence signals that the initial interpretation was wrong and must be corrected. The suppression of an incorrect interpretation measured by a response to a comprehension question was used to index for cognitive inhibition. The process of cognitive inhibition can be more difficult to measure as it is harder to isolate than response inhibition. The ADHD participants had some difficulty supressing the misinterpretation but this difference can be explained by weak reading ability. The results of this study showed that cognitive inhibition was not affected in individuals with ADHD (Engelhardt et al., 2008), and these findings were supported in studies with children and adults with ADHD (Barkley, 1997; Carr et al., 2006; Gaultney et al., 1999). Response inhibition studies (Conners et al., 2003; Corkum & Siegel, 1993; Crosbie et al., 2013; Dimoska et al., 2003;

Epstein et al., 2003; Johnstone et al., 2009; Liotti et al., 2007, 2010; Overtoom et al., 1998; Wodka et al., 2007; Woltering et al., 2013) still dominate the ADHD research and studies focusing on cognitive inhibition are scarce (Barkley, 1997; Carr et al., 2006; Engelhardt et al., 2008; Gaultney et al., 1999).

Anxiety and Inhibitory Control

Anxiety has been linked to deficits in cognitive control affecting specifically inhibition, shifting and updating (Eysenck et al., 2007; Berggren & Derakshan, 2013). Attentional Control Theory examines how anxiety affects cognitive control and suggests that the role of stimulus-driven attention is increased due to augmented attention to threat in individuals with anxiety (Eysenck et al., 2007). Threat-related attentional bias has been found in anxiety disorders and in individuals with high trait anxiety (Cisler & Koster, 2010; Zvielli et al., 2014). An increase in the stimulus driven attentional system leads to disengagement of the goal-directed attention network, thus affecting cognitive task performance unless compensatory strategies and enhanced effort are employed (Eysenck et al., 2007; Hum et al., 2013). Overall, these findings suggest that cognitive inhibition may be affected in anxious individuals as they have difficulty in filtering out distracting information and focusing on the goal at hand.

Clinical anxiety has been related to excessive engagement of the behavioural inhibition system (Epstein et al., 1997; Gray & McNaughton, 2000; Grillon et al., 2017; Quay, 1997; Sylwan, 2004). Rodent models suggest that anxiety activates the behavioural inhibition system, which triggers a set of defensive responses, including response inhibition (Gray & McNaughton, 2000; Grillon et al., 2017). However, human studies of response inhibition in anxious individuals have yielded mixed results. For example, Oosterlan and colleagues (1998) used a CPT to investigate inhibition in anxious children. They found that anxious children and typical controls

did not differ in their inhibitory functions, suggesting that anxious children may only show enhanced response inhibition in situations that trigger their overactive behavioural inhibition system (BIS). A study by Grillon and colleagues (2017) may help to answer what happens when the BIS is triggered in anxious individuals. They used a Go/NoGo task with shock and safe conditions to examine inhibitory control in clinically anxious and healthy individuals. Healthy participants had increased NoGo commission errors in safe conditions compared to anxious participants. However, in the threat conditions as state anxiety increased response inhibition also increased for all participants. In addition, the clinically anxious group exhibited excessive response inhibition (fewer NoGo commission errors) and more errors on Go conditions in both the safe and shock conditions (Grillon et al., 2017). These results suggested that anxiety may influence response inhibition in two ways: decreased commission errors are related to the beneficial effect of defensive reactivity and increased omission errors are related to the detrimental effect of distracting anxious thoughts.

Other studies have found response inhibition deficits in individuals high in trait anxiety (Xia et al., 2020). Xia and colleagues (2020) conducted an ERP study that examined the role of trait anxiety on inhibition using a Go/NoGo Task. They found that the high trait anxious group made more mistakes in NoGo trials compared to the low anxious group, but there was no group difference in the Go condition as few mistakes were made. Additionally, ERP results showed that the high trait anxious group had smaller and later frontal NoGo N2 (which the authors interpreted as reflecting “the motor plan prior to the motor execution inhibitory process”) and larger and later parietal NoGo-P3 (“reflects later monitoring and evaluation of the inhibition process”) (Xia et al., 2020 p.1). Xia and colleagues (2020) suggested that these results indicated that response inhibition deficits exist in the highly trait anxious group, and it was due to aberrant

premotor inhibition control and inefficient evaluation and monitoring. However, it is possible that these results are due to a slower evaluation with the same motor response speed, leading to more errors. Overall, the role of anxiety and trait anxiety on response inhibition remains unclear (Grillon et al., 2017; Oosterlan et al., 1998; Xia et al., 2020).

In summary, clinical ADHD and ADHD-traits have been related to poorer response inhibition, indexed by more errors in various Go/NoGo Tasks (Conners, 2002; Crosbie et al., 2013; Wodka et al., 2007 Woltering et al., 2013). Research indicates that ADHD does not seem to influence cognitive inhibition, although there is less research focusing on this area and it is not as well understood as response inhibition (Barkley, 1997; Carr et al., 2006; Engelhardt et al., 2008; Gaultney et al., 1999). On the other hand, anxiety has been related to attentional bias to threat which is associated with reduced cognitive inhibition since more attentional resources are allocated to potential threat than task performance (Cisler & Koster, 2010; Eysenck et al., 2007). Behavioural studies suggest that anxiety is characterized by excessive response inhibition (Grillon et al., 2017); however, one study looking at the neurophysiological correlates of response inhibition suggested reduced response inhibition in anxiety (Xia et al., 2020).

Overall the results suggest that both anxiety and ADHD are separately associated with hypo and hyper arousal states, low registration and sensory sensitivity in addition to cognitive and response inhibition. These findings support the notion that internalizing and externalizing disorders have common underlying traits or a common genetic factor that lead to vulnerabilities for symptoms in both spectrums (Willner et al 2016; Weiss et al., 1998). Another possibility is that these disorders are linked to a common p-factor, a general psychopathology dimension (Caspi et al., 2014; Caspi & Moffitt, 2018).

Comorbidity of Anxiety and ADHD

Anxiety is comorbid with ADHD, with estimates ranging from 25% to 40% (D'Agati et al., 2019; Spencer et al., 1999; Tannock, 2009). Anxiety is equally linked to the inattention subtype and the hyperactivity/impulsivity subtype of ADHD in adults (Gonzalez-Castro et al., 2015; Prevatt et al., 2015); however, the combined subtype has been shown to have significantly higher levels of trait anxiety (Gonzalez-Castro et al., 2015).

Anxiety, ADHD and Sensory Processing Patterns. Research has been done on SPPs in both anxiety and ADHD; however, there is limited research in anxiety-ADHD comorbidity. One study by Reynolds and Lane (2009) examined whether sensory over-responsivity (SOR) was related to increased anxiety levels in children with ADHD. SOR is a sensory modulation disorder defined by quicker, longer or more intense responses to stimuli. The findings showed that children who had ADHD and SOR were significantly more anxious than both the ADHD-only and the control groups (Reynolds & Lane, 2009).

In another study Lane and colleagues (2010) found that anxiety was related to SOR in both typically developing and ADHD groups, suggesting that ADHD should be considered in conjunction with anxiety and sensory responsivity. The authors speculated that individuals with ADHD and SOR may be sharing similar bottom-up processes that can lead to hypervigilant states. The hypervigilant pattern of SOR has behavioural outcomes such as restlessness, which are similar to the hyperactive-impulsive presentation of ADHD. In addition, individuals with SOR and ADHD with comorbid anxiety may have deficits in prefrontal cortex/hippocampal synaptic gating. However, more research is necessary to support these relationships (Lane et al., 2010).

Anxiety, ADHD and Inhibitory Control. In terms of inhibitory control, the research with individuals who have comorbid anxiety and ADHD has led to mixed results (Epstein et al., 1997; Hare et al., 2017; Klymkiw et al., 2017; Maric et al., 2018; Oosterlan et al., 1998; Ruf et al., 2017). First, CPT performance is impaired in children with ADHD, but the CPT has not been extensively used in anxiety. Epstein and colleagues (1997) investigated the differential effects of physiological and cognitive anxiety on inhibitory control using worry/oversensitivity and physiological anxiety subscales of the self-report Revised Children's Manifest Anxiety Scale. They found that in individuals with ADHD heightened physiological anxiety had increased response inhibition while cognitive anxiety (worry) decreased response inhibition. The authors suggested that some forms of anxiety increase response inhibition, while other cognitive forms increase activation or arousal, leading to impulsivity. Therefore, cognitive anxiety appears to decrease response inhibition, which may be due to a bottom-up increase in arousal but a top-down decrease in vigilance since the prefrontal cortex is occupied. Ruf and colleagues (2017) found that ADHD-diagnosed adolescents with high trait anxiety performed better on measures of reaction time, sustained attention, and motor variability. Also, in both ADHD and non-ADHD groups, high trait anxiety predicted faster Stop Signal reaction time, which suggests better response inhibition. In a recent study, we showed that individuals high in inattention and trait anxiety showed slower reaction times in a distractor AX CPT task, suggesting poorer response inhibition in these individuals (Hare et al., 2017). However, in this study neither hyperactivity nor impulsivity interacted with trait anxiety to affect reaction time (Hare, 2017). These results were explained considering Sluggish Cognitive Tempo characterized by inconsistent alertness and orientation that may explain the delay in reaction time (McBurnett et al., 2001). Sluggish Cognitive tempo is linked to anxiety and inattention but only when hyperactivity and impulsivity

is not present. A recent meta-analysis revealed that children with comorbid ADHD and anxiety disorder performed better in response inhibition compared to ADHD only children (Maric et al., 2018). The authors suggested that the mechanisms underlying anxiety disorders might prevent inhibition problems in children with ADHD, especially the ones who were not on medication.

In summary, the results of the behavioural studies investigating the effect of comorbid anxiety and ADHD on response inhibition have been mixed. ADHD has typically linked to reduced response inhibition but unaffected cognitive inhibition. Anxiety has had mixed results in terms of response inhibition, but cognitive inhibition is negatively affected due to an attentional bias to threat. Some studies suggest that since anxiety should increase behavioural inhibition, it may help to mitigate the poor response inhibition in those with ADHD (Ruf et al., 2017). Using a behavioural approach only allows us to see the outcome of behaviour, where it may be important to understand the neurophysiological responses to better explain the discrepancies in these results. As both the SPPs included in this study (LR & SS) are passive, it is possible that performance may not be different, but their neural processing may be different due to distinct neurological thresholds. To examine the effect of SPPs, ADHD trait and trait anxiety, this study applied an ERP approach that allows cognitive processing to be studied more directly. An ERP approach, in conjunction with differences in individual traits, may allow us to examine whether inhibitory problems are due to an over-active or under-active inhibition system.

Event-Related Potentials and Inhibitory Control

This study takes an ERP approach to studying inhibitory control as ERPs provide information about the neural responses underlying the cognitive processes occurring during the task that cannot be observable using behavioural measures. For example, a participant may perform accurately and quickly on a task; however, they may put in more cognitive effort than

other participants with similar performance. This critical information would be missed without using ERPs. An ERP component is defined as specific psychological process or neural event represented by a time-locked scalp-recorded voltage change (Kappenman & Luck, 2012). ERPs are not large events; multiple EEG epochs are combined to form an average ERP waveform that allows the events to become visible.

ERPs are measured both by amplitude and latency; additionally, they are labelled by their polarity (i.e. positive or negative going). The N2 is a negative going component that is elicited around 200 to 400 milliseconds after stimulus presentation (Klymkiw et al., 2017). There are different types of N2 components, such as the N2a, N2b and N2c, which reflect similar but different cognitive functions. A common task used to elicit a N2 is a Go/NoGo task in which a participant responds to specific stimuli (Go) and withholds a response to other stimuli (NoGo). The N2b (NoGo N2) is larger when a participant successfully inhibits their response to a rare NoGo stimulus, and smaller when they correctly respond to a Go stimulus, as heightened neural activation is demonstrated when inhibiting the pre-potent motor response (Falkenstein et al., 1999; Nieuwenhius et al., 2003). Research suggests that the anterior cingulate cortex, a brain area located in the medial frontal cortex, is the neural generator for the N2 (Feldman & Freitas, 2019; Wang, et al., 2005; Yeung, et al., 2004). The N2 has been used to study inhibitory control in both clinical and non-clinical populations. As reviewed elsewhere in this review, inhibitory control problems have been linked to ADHD and anxiety; and an ERP approach, in conjunction with differences in individual traits, may allow us to examine whether inhibitory problems are due to an over-active or under-active inhibition system.

ADHD and N2. Previous research showed that youth with ADHD had significantly smaller N2 amplitudes to NoGo stimuli compared to youth without ADHD (Albrecht et al.,

2005; Dimoska et al., 2003; Johnstone et al., 2009; Liotti et al., 2007, 2010). This smaller NoGo N2 amplitude in combination with longer Go mean reaction times and increased omission and commission errors suggest that there is deficient inhibitory control in children with ADHD (Dimoska et al., 2003). Senderecka and colleagues (2018) used a Stop-Signal Task to measure response inhibition in children and found that children with ADHD-combined type have greater amplitude and longer N2 latency than typically developing children in only successful stop-signal trials. They suggest that these results contradicted most previous reports; however, N2 amplitude has been consistently larger in participants who had slower responses (Dimoska et al., 2006; Falkenstein et al., 1999; Senderecka et al., 2018). Therefore, this larger N2 amplitude could be due to the slower response in this ADHD group. In adults with ADHD, the N2 had a longer latency but amplitude did not differ from controls in a Go/NoGo task (Fisher et al., 2011). Additionally, ADHD subjects showed an enhanced response inhibition in Go trials (a finding that was unexpected), with excessive omission errors associated with significantly larger N2 amplitudes. Reduced activity in the right frontal dorsolateral cortex and in the posterior cingulate of the ADHD group was shown to be potential sites in a source current density estimation. Fisher and colleagues (2011) suggested that these results reflected impaired response inhibition and beyond that, a general dysregulation of behavioural inhibition. In sum, these studies show that individuals with ADHD have reduced task performance indicating reduced response inhibition and they have different N2 amplitude and/or latencies than individuals without ADHD.

Anxiety and N2. Studies of N2 in clinically anxious and high trait anxious individuals have yielded mixed results with some studies showing larger NoGo N2 amplitude (Hum et al., 2013; Righi et al., 2009), no difference in N2 amplitude (Yang & Li, 2014) and even smaller N2 amplitude (Xia et al., 2020). Hum and colleagues (2013) found that anxious children had

significantly greater frontal NoGo N2 amplitudes to calm faces in an emotional face Go/NoGo task. The researchers interpreted this finding as greater neural resources were dedicated to response monitoring or inhibitory control in children with anxiety (Hum et al., 2013). Additionally, in the anxious group there were no differences in neural activation in emotional face types or trial types (Go vs NoGo), although there were differences in the typically developing children. This could be due to a hypervigilant regulatory style that does not discriminate between task demands and shows an increase in cortical activation regardless of the emotional content of the stimuli (Hum et al., 2013).

The few studies that examined trait anxiety and N2 in university populations have also revealed mixed results (Righi et al., 2009; Xia et al., 2020; Yang & Li, 2014). Righi and colleagues (2009) found that N2 amplitude was larger in high trait anxious females compared to low trait anxious females. Yang and Li (2014) found no significant difference in NoGo N2 amplitude between high and low trait anxious groups. Lastly, Xia and colleagues (2020) found that the high trait anxious group had a smaller and later NoGo N2 compared to the low trait anxious group. Therefore, it is unclear whether NoGo N2 amplitude and response inhibition is affected by anxiety and therefore warrants further investigation. One explanation for these discrepancies may be due to the differences in experimental parameters. For example, the Xia and colleagues (2020) implemented shorter stimulus presentation (150ms) with two pairs of stimuli, but Righi and colleagues (2009) had longer stimulus presentation (200ms) with one special stimulus. Therefore, there may be enhanced difficulty in inhibition the NoGo stimuli in the task employed by Xia and colleagues (2020). Another aspect that can change task demands and performance is the ratio of Go to NoGo stimuli, some studies have a ratio of (2:1), whereas others use (1:1). Overall, the results of the studies using neurophysiological correlates of

inhibitory control are unclear in anxious participants. This could be due to differences in experimental designs or due to individual differences in cognitive mechanisms used by different people.

Anxiety, ADHD and N2. Only handful of studies have investigated the neurophysiological correlates of inhibition in combined anxiety and ADHD. In a recent study, Klymkiw and colleagues (2017) found that youth with comorbid ADHD and anxiety exhibited larger NoGo N2 stimuli compared to ADHD-only youth when completing a visual Go/NoGo task. They suggested that anxiety enhances attention allocation when attentional and/or impulse control is required. When indexing impulse control, N2 amplitudes were significantly larger in the Go rather than NoGo condition both in the ADHD and ADHD/anxiety group. Typically, N2 amplitudes are higher in NoGo conditions than Go conditions (Falkenstein et al., 1999; Nieuwenhius et al., 2003) but this reverse pattern has been documented in both youth with ADHD (Groom et al., 2010) and youth with anxiety (Hum et al., 2013). Klymkiw and colleagues (2017) suggested that this reverse pattern may be due to the rewards not being large enough on NoGo trials for youth with ADHD. The combination of anxiety and ADHD leads to an increase in the neural response related to response inhibition.

Overall, the literature has been mixed as to how anxiety or ADHD affect N2 amplitude. In anxious individual some studies have suggested larger NoGo N2 amplitude (Hum et al., 2013; Righi et al., 2009), no difference in N2 amplitude (Yang & Li, 2014) and even smaller N2 amplitude (Xia et al., 2020). In ADHD individuals most research suggests significantly smaller N2 amplitudes (Albrecht et al., 2005; Dimoska et al., 2003; Johnstone et al., 2009; Liotti et al., 2007, 2010), but some other studies have shown longer N2 latency (Fisher et al., 2011) or longer N2 latency and greater amplitude (Senderecka et al., 2018) or. These differences could exist due

to differences in the measures used, different types of Go/NoGo tasks and differences in the groups studied (i.e., age or clinical and community samples). However, the results of these studies suggest that the N2 component is affected in both groups. Neurophysiological correlate of N2 suggests that there is abnormal inhibitory control as most clinical groups differ from the general population.

Present Study

The overarching goal of this ERP study was to investigate how individual differences in sensory processing patterns (SPPs), ADHD-traits and trait anxiety influence inhibitory control in university students. ADHD and anxiety are often comorbid, and their comorbidity has been linked to challenges in social, academic, self-regulation and self-organization (Jarrett, 2016; Jensen et al., 2001; Mikami et al., 2011). Individually, both anxiety and ADHD have been related to atypical sensory processing (Dunn & Bennet, 2020; Engel-Yeger & Dunn, 2011; Ghanizadeh, 2011; Lane et al., 2010; McMahon et al., 2019). However, no previous research has been conducted examining their combined effects on cognitive functions. As seen with the comorbidity with ADHD and anxiety, the interactions of comorbid conditions should be investigated, as the impact of multiple challenges in affective, social, and cognitive domains can be different than the impact of each individual condition. This thesis adopted the dimensional approach in studying the neurodevelopmental and continuous nature of mental disorders and the findings addressed the complex pattern of sensory-affective-cognitive relationships underlying the comorbidities (Hengartner & Lehmann, 2017). In this study sensory processing was conceptualized as a transdiagnostic mechanism and vulnerability factor that can negatively impact cognitive outcomes, especially when it interacts with other vulnerability factors, such as heightened anxiety and ADHD-traits (Harrison et al., 2019). In accordance with this dimensional

framework, sensory, affective, and behavioural constructs were studied as continuous traits rather than discrete diagnostic categories.

Hypotheses

Hypothesis 1: The effect of low registration on inhibitory control (N2 amplitude) was expected to be a function of the level of ADHD-traits (inattention, hyperactivity, impulsivity) and trait anxiety; therefore, a significant three-way interaction involving low registration, ADHD-traits and trait anxiety was hypothesized in all three inhibitory conditions.

Hypothesis 2: The effect of sensory sensitivity on inhibitory control (N2 amplitude) was expected to be a function of the level of ADHD-traits (inattention, hyperactivity, impulsivity) and trait anxiety; therefore, a significant three way interaction involving sensory sensitivity, ADHD-traits and trait anxiety was hypothesized in all three inhibitory conditions.

Methods

Participants

Seventy-seven university students (37 males, 39 females and 1 other gender) ages 18 to 26 were recruited through an online recruitment software for the department of Psychology (SONA) and through posters displayed around the University. Seventeen participants were excluded from the data analysis due to technical problems, failure to complete the task, unusable EEG data and incomplete questionnaires. Final sample consisted of 60 participants (28 females 47%; ages 18 to 26; M= 20.5, SD= 2.23).

Demographics

The mean age of the participants included in the final sample (N=60) was 20.5 (*SD*=2.23, Min=18, Max=26). On average participants were in their 2.38 year of school (*SD*=1.53, Min=1, Max=6). Majority of participants (76.7%) |were native English speakers. Six participants (10%) self-reported problems with attention or concentration, 3 participants (5%) self-reported problems with hyperactivity. Only 1 person was on medication related to problems with attention. Fourteen participants (23%) self-reported problems with mood and 3 were on medication for their problems with mood. Two participants (3%) reported other psychiatric problems.

Measures

Questionnaires

Health History Questionnaire (HHQ). A brief health history questionnaire developed for the previous studies was used to collect information regarding participant's age, sex, mental and physical health, medication use, and other non-prescription substance use (Thorne et al, 2017).

Adolescent/Adult Sensory Profile (AASP)**.** To measure sensory processing patterns, participants completed the Adolescent/Adult Sensory Profile (Brown & Dunn, 2002) used extensively in the area of occupational therapy and research. The AASP is a 60 –item self-report questionnaire that measures the frequency of behavioural responses to sensory events. Items are scored on a 5-point Likert scale ranging *almost never* to *almost always*. The questionnaire has 4 scales; low registration, sensation seeking, sensory sensitivity, and sensation avoiding. In this study only low registration (LR) and sensory sensitivity (SS) scales were used in the analyses. Each scale has 15 statements representing individual's sensory experiences in different modalities (Taste/Smell Processing, Visual Processing, Auditory Processing, Touch Processing, Activity Level and Movement Processing) as well as behavioural/self-regulatory reactions to these experiences.

The following are some examples for the low registration and sensory sensitivity scales (Brown & Dunn, 2002). **Low Registration**: "I don't smell things that other people say they smell", "I trip or bump into things", " I don't seem to notice when someone touches my arm or back" (p.65). In general, high scores in this scale indicates a person who "…tend to miss or take longer to respond to stimuli that others notice" (p.35). On the other hand, low scores may indicate a person who is generally in tune to sensory stimulation, but not necessarily over sensitive (Brown & Dunn, 2002). **Sensory Sensitivity:** "I am distracted if there is a lot of noise around" "I like to go to places that have bright lights and that are colorful" (p.85). In general people who score high in SS notice stimuli more quickly and they are more responsive to sensory stimuli. They are also more easily distracted and disturbed by the sensory stimuli. Low scores in SS may indicate a person who is not generally distracted or overwhelmed by sensory stimuli (Brown & Dunn, 2002).

Conners' Adult ADHD Rating Scale-Long Version (CAARS:S-L). ADHD symptomology was assessed by CAARS (Conners et al., 1999). The scale consists of 66 items with a 4-point Likert scale, ranging from "not at all true" to "very much true." In addition to several clinical indices, the CAARS has four factor-derived subscales: inattention/memory problems, hyperactivity/restlessness, impulsivity/emotional lability, and problems with self-concept. The scale has high internal reliability with alpha coefficients between .86 and .92 (Erhardt, Epstein, Conners, Parker, & Sitarenios, 1999) and high test-retest reliability ranges from .88 to .91 (Erhardt et al., 1999). In this study inattention/memory (11 items), hyperactivity/restlessness (12 items) and impulsivity/emotional lability (12 items) scores were used to quantify three core ADHD-traits in a non-clinical sample. In the assessment manual, the characteristics of high scores in inattention/memory are defined as " learn(ing) more slowly, have problems organizing and completing tasks and have trouble concentrating", high scores in hyperactivity/restlessness are defined as "difficulty working at the same task for very long, and feel more restless and 'on the go" than others (Conners et al., 1999, p.24), and high scores in impulsivity/emotional lability are defined as " engage in more impulsive acts than others, mood change quickly and often, are more easily angered and irritated by people" (p. 24). CAARS can be used as a clinical and a research instrument.

State Trait Anxiety Inventory (STAI). Trait anxiety was measured by the STAI (Spielberger et al.,1983). The STAI includes 40 items; 20 items for the trait anxiety subscale and 20 items for the state anxiety subscale, each rated on a 4-point Likert scale from "almost never" to "almost always." Trait anxiety is defined as a more stable temperamental characteristic, and the state anxiety is defined as situational. High scale scores indicate higher anxiety levels. The scale has high internal reliability with alpha coefficients between .86 to .96, and moderate test-

retest reliability with a range of .65 to .75 (Spielberger et al., 1983). In the present study only trait anxiety score was used.

The ERP Paradigm

Distractor AX-Continuous Performance Task (d-AX-CPT). The task was adapted from Tekok-Kilic et al., (2001). E-Prime software Version 2 was used to create the stimuli. The stimuli consisted of 11 letters of the alphabet (A, B, C, D, E, F, G, H, J, L, X). The letters and distractor images were black, and the background was white. A total of 1270 letters were presented in a quasi random sequence in the middle of the computer screen, one letter at a time. Each letter was presented for 200 ms, with an interstimulus interval (from stimulus offset to stimulus onset) of 800 ms. The participants were required to press two buttons with right and left thumbs on a response pad quickly and accurately to the letter X, only when it is preceded by the letter A and not to respond to any other letter sequences. Two main conditions of the task relevant to this study were (1) A-X letter sequences (Go conditions, total of 100 trials) and (2) A-not X letter sequences (NoGo conditions, total of 100). Distractor stimuli in the form of simple line drawings (see Appendix B) were presented in 50% of the time during both Go and the NoGo conditions. The goal of adding distractors to the task was (1) to increase the task demands (2) to create different conditions in which the participants needed to inhibit the stimuli that was not related main task (see Table 2 for the total number of Go and NoGo conditions with/without distractors). The distractors were presented approximately 200 ms after the presentation of the letter A for a duration of 200 ms (see Figure 1) Distractors could appear in one of 8 locations equally: all 4 corners and either directly above, below or beside the letter being presented. The total duration of the task was 22 minutes presented in two blocks separated by a short break (Block A= 13.5 minutes, Block B=8.5 minutes).

Task Instructions. The following instructions were given to participants before the start of the practice block of the experiment:

Letters of the alphabet will be presented on the center of the screen (point to center of the screen). Your task is too look for an X that comes before an A. As soon as you see X after an A immediately press these buttons (point to #1 and #4 on response pad) with the thumb of your left and right hand. If you see any other letters, don't press any buttons. For example, if you see an A without an X after it, or if you see an X that did not have an A before it you don't press. You may see pictures on the screen, just continue with the task at hand.

Table 2

Go (A-X) and NoGo (A-not-X) Conditions

Go and NoGo Conditions	Description	Number of stimuli
No Distractor	No distractor line drawing between A-X and A-not-X	50/50
Distractor- Pleasant	Pleasant or neutral distractor line drawing between A-X and A-not-X	25/25
Distractor- Unpleasant	Unpleasant distractor line drawing between A-X and A-not-X	25/25

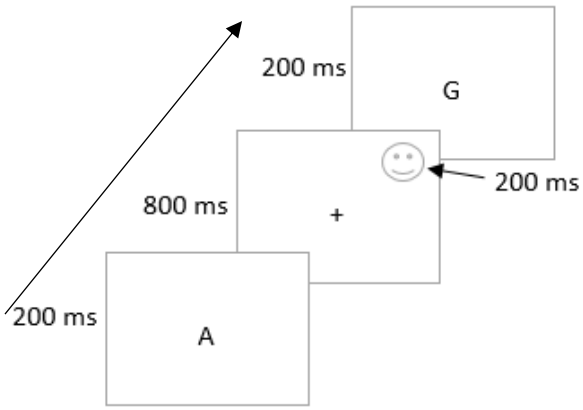


Figure 1

NoGo Trials with Distractors.

Table 3

Type of Inhibitory Control Based on Task Demands

	No Distractor	**Distractor**
Go Conditions	Control	Cognitive Inhibition
NoGo Conditions	Response Inhibition	Cognitive & Response Inhibition

Distractor stimuli. Distractors were 100 simple line drawings (50 pleasant/neutral, and 50 unpleasant) which were drawn by hand, photographed and uploaded into Krita Version 3.1.4. (Hare et al., 2017, See Appendix B for distractors). Images were traced by adding a layer onto the drawing with a brush (Basic_tip_default) and was 10.36 thickness, with weighted smoothing. The brush was at full opacity and the colour black was used. A white layer was added and inserted under the trace to provide a white background. Files were saved and then uploaded into Microsoft Paint where they were cropped and resized to 250x250 pixels, in order to match the sizing on E-Prime. Pictures were drawn to be simple enough that they could be recognized in 200ms. Few lines were used when possible to control for luminance. The line drawings (Hare et al., 2017) were determined as pleasant/neutral or unpleasant at the time of drawing by the artist and have not been normed previously but participants of this study rated the pleasantness of these distractors after they completed the d-AX-CPT (see next section for a more detailed explanation).

Post-Task Memory and Rating Questionnaire (PMRQ). The recognition task consisted of 100-line drawings that were presented as distractors during the CPT (See Appendix for the pleasantness ratings and memory scores). Participants were asked whether they had seen the image during the task (yes=1, maybe=2, no=3), all of which were presented once. Regardless

of their memory of the image, participants were then asked how pleasant they would rate the image on a scale of 1 to 7 (1-unpleasant, 4-neutral, 7-pleasant). This task took approximately 10 minutes to complete. This task was programmed in Eprime 2.0 Software. In this study the recognition memory and image ratings were analyzed (See Hare, 2017).

Electrophysiological Recording

Participants were tested in the Developmental Neuroscience Laboratory (DNLab), housed in the Department of Child and Youth Studies. Continuous EEG was acquired in a sound attenuated electrically shielded chamber using Netstation (version 4.5.1, EGI, Inc**.**) a 128-channel HydroCel Geodesic Sensor Net and 300 NetAmps amplifier (Electical Geodesics, Inc., Eugene, Oregon). The EEG signal was online referenced to the vertex electrode (Cz) and sampled at a rate of 500Hz with a band-pass filter from 0.01 to 100 Hz. Impedances were kept below 100 kΩ.

Data Processing

Continuous EEG was processed offline with Brain Vision Analyzer (BVA) 2.0 (Brain Products 2.0). First EEG was filtered between 1 Hz to 30 Hz then messy channels were removed, electrodes of interest were rarely removed. Electrode 6 on one of the nets malfunctioned and the electrode 113 was often noisy, therefore these two channels were removed from all participants. Since electrode 6 was of interest, it was interpolated by pooling the surrounding electrodes (Channels 5, 7, 12, 13, 106 and 112) after a baseline and ocular correction. After that, the data were referenced to the average.

Segmentation and Baseline Correction. Continuous EEG was segmented into individual trials starting 200 ms prior to and ending 1000 ms after stimulus onset, and were baseline corrected from -200 to 0 ms (a representative epoch of prestimulus neural activity). This

was done for the following 4 conditions: Go Distractor, Go No Distractor, NoGo Distractor and NoGo No Distractor (See p. 43 for the detailed explanations of these conditions). There were 50 trials in each condition. Only correct trials were included. The trials with omission and commission errors were deleted. The distractors were either pleasant/neutral or unpleasant (See page 34 for dAX CPT description). In the task there were 50 unpleasant stimuli that were split evenly between Go and NoGo trials. However, only 13/50 of the images were rated as unpleasant (1, 2, or 3) by 75% of the participants and 29/50 images were rated as unpleasant by 65% of participants. Due to the low number of images rated unpleasant, these categories were collapsed into a total Distractor Condition.

Artifact Rejection. A Gratton & Coles ocular correction was performed (Gratton et al., 1983). Segments with a subset of channels of interest were then subjected to an automated artifact rejection with a maximum allowed voltage change of 200 μv between consecutive data points, and a maximum amplitude limit of ±100 μv for a single data point.

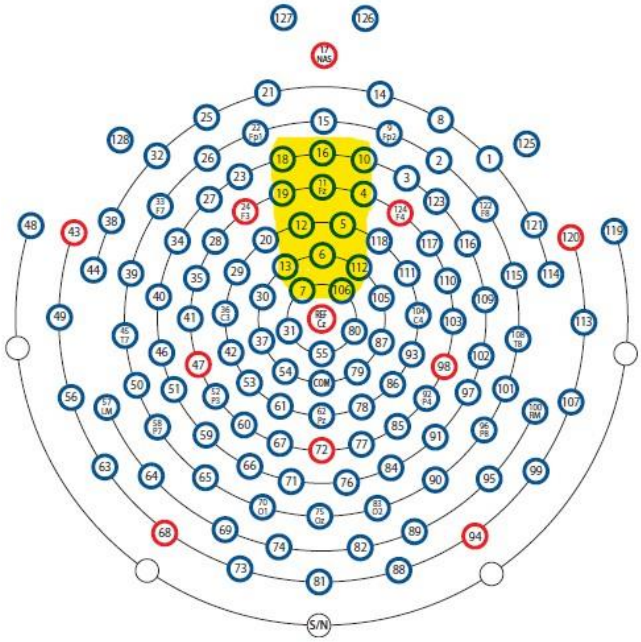
Averaging. Channels that remained after cleaning were then averaged across the 4 conditions (Go Distractor, Go No Distractor, NoGo Distractor and NoGo No Distractor). Participants had to keep at least half of the trials to be included in the final sample. The averages were then exported for peak picking.

Peak Picking. In order to define the time window for the N2 component, the grand averages from four conditions were calculated: (1) NoGo -No Distractor (NoGo_ND), (2) NoGo- Distractor (NoGo_D) (3) Go Distractor (Go_D), (4) Go No Distractor (Go_ND). The grand averages revealed that the NoGo N2 peak occurred at 200-300ms. Same latency window was used to pick maximum negative going peak as N2 in the Go conditions. As frontal central electrodes are the prominent sites for NoGo N2 (Weissflog et al., 2013), in this study, electrodes

4, 5, 6, 7, 10, 11, 12, 13, 16, 18, 19, 106 and 112 were used to determine N2 amplitude via the semi-automatic peak picking function of BVA 2.0 (See Figure 2). The baseline to peak values were calculated and the max peak (highest amplitude) from the subset of electrodes of interest was chosen for each participant (Weissflog et al., 2013).

Figure 2

Electrodes of Interest for N2 Component.



Procedure

This study received clearance by Brock University's research ethics board (REB #17-105 see Appendix C). All participants gave informed consent and received 2 hours research credit upon completion. Participants' heads were measured, and the EEG nets were put on. The participants completed two blocks of the d-AX CPT presented on a computer monitor while continuous EEG were recorded. After the recording was finished the participants completed the Post-Task Memory and Rating Questionnaire (PMRQ) on the computer and eight self-report questionnaires: Adult Temperament Questionnaire (Rothbart et al., 2000), Adolescent/Adult

Sensory Profile (Brown & Dunn, 2002), Beck Anxiety Inventory (Beck & Steer, 1993), Conners' Adult ADHD Rating Scales (Connors et al., 1999), State Trait Anxiety Inventory (Spielberger et al., 1983), Health History Questionnaire (Thorne et al, 2017), and Intolerance of Uncertainty Questionnaire (Carleton et al., 2007). For the purposes of this study only STAI, AASP and CAARS were analysed. After completing the questionnaires, participants received a debriefing letter and any questions they had were answered.

Analyses and Results

Data Screening and Missing Data

Three conditions were chosen for testing the hypotheses of this study although there were more letter sequences present in the AX-CPT. These conditions of interest were Go Distractor, NoGo Distractor and NoGo No Distractor conditions. Each of these conditions were designed to elicit a N2 response that has been shown to correlate the inhibitory processes (Dimoska et al., 2003; Fisher et al., 2001; Klymkiw et al., 2017). Although the Go No Distractor condition was processed, this condition was not included in the main models testing the moderated effects of sensory processing on N2 amplitude as no significant inhibitory activity was expected in this condition.

Before conducting the statistical analyses, each of the variables of interest were examined for missing data from the initial sample of 77. Overall, 2 participants were missing LS & SS scores and were removed for not completing the dAX-CPT. Four participants were missing trait anxiety scores, 2 of them were removed for not completing the dAX-CPT. The following participants were missing data points in our sample of 60 and were included in the analysis. For 1 participant there was 1 missed question (Q21) on the AASP, which was replaced according to the technical manual (Brown & Dunn, 2002). Inattention, hyperactivity and impulsivity had no missing scores, although 3 participants missed 1-3 questions which was replaced as suggested in the CAARS technical manual (Conners et al.,1999).

Testing Assumptions for Moderation Models

Univariate Assumptions

There were no univariate outliers identified as all standardized z-scores fell within +/- 3 standard deviations (*SD*) of the mean (Field, 2013). The assumption of normality was met as

visual inspection revealed the histograms of the model variables followed a bell-shaped curve and this was supported by skewness and kurtosis values which fell within the normal range when using +/-2 *SD* above the mean as anchors (Field, 2013). The assumption of linearity was met by visually inspecting a scatterplot with a Loess line for each criterion variable and each of the predictor variables. Although visual inspection suggested that 2 models (Go Distractor in Low Registration and Sensory Sensitivity) looked curvilinear, this was due to 2 outliers. These cases were defined as multivariate outliers, but they did not affect the results, so the decision was made to keep them in the analyses.

Multivariate Assumptions

Multivariate outliers were considered any standardized residual scores outside of +/-3 SD about the mean. There were 2 multivariate outliers, however, including or excluding the outliers did not significantly affect the models therefore the outliers were retained. The assumption of normality was met in each model by examining a histogram of the standardized residual scores and a Probability-Probability Plot. The assumption of homoscedasticity was met in each model by visual inspection of a scatterplot with the standardized residual scores and the standardized predictor values. The assumption of independence was met using a Durbin-Watson test, as all the model values fell within the ideal range of 1.5 and 2 (Hair et al., 1995). The assumption of multicollinearity was met as none of the Variance Inflation Factor scores were substantially higher than 1 and were below 10 (Bowerman & O'Connell, 1990; Myers, 1990). Focal predictors (LR and SS) and primary moderators (inattention, impulsivity & hyperactivity) and the secondary moderator (trait anxiety) were centered around their sample mean before the interaction terms were computed and the centered variables were included in the regression.

Overview of the Analyses

Hit Rate (HR), False Alarms (FA), Response Time (RT) and N2 amplitude and latency were compared for Distractor vs. No Distractor Go and NoGo conditions using t-tests and ANOVAs. The bivariate correlations among performance variables and self-report questionnaire scores were obtained (See Tables 5 & 6).

Main hypotheses were tested with separate moderated moderation models using PROCESS macro Model 3 (Hayes, 2013, see Figures 3 & 4 for the model representations) via SPSS Version 26 Software (SPSS-26)[1]. Low Registration and Sensory Sensitivity were analysed as focal predictors (X) in their own 9 models. The outcome variable (Y) was the N2 amplitude measured separately in all three inhibition conditions/trials (Go Distractor, NoGo-Distractor and NoGo No Distractor). The primary moderator was the individual ADHD-traits (inattention, hyperactivity and impulsivity) (W), and the second moderator was the trait anxiety (Z).

In each moderated moderation model, the significant 3-way interactions examining sensory processing patterns, ADHD traits and trait anxiety, were probed by using a series of post hoc regression equations, referred to simple slope analysis[1]. For example, to test the relationship between Low Registration and Go Distractor N2 amplitude as a function of impulsivity and trait anxiety, simple slopes analyses were conducted to observe the differences in slopes by impulsivity and to determine whether these slopes differed significantly from zero when the level of Trait Anxiety was high (1 standard deviation above the mean), moderate (the mean) and low (1 standard deviation below the mean) (See Table 7 in Appendix A for this example).

[1] When the analyses did not yield significant 3-way interactions any significant 2-ways involving the focal predictor and the moderator were analysed (see Figure 7 & 8).

Figure 3

Conceptual Model (PROCESS Model 3)

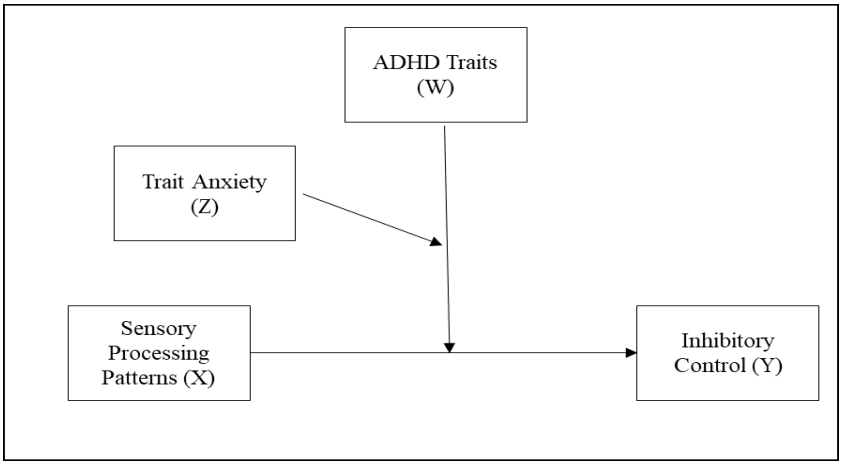
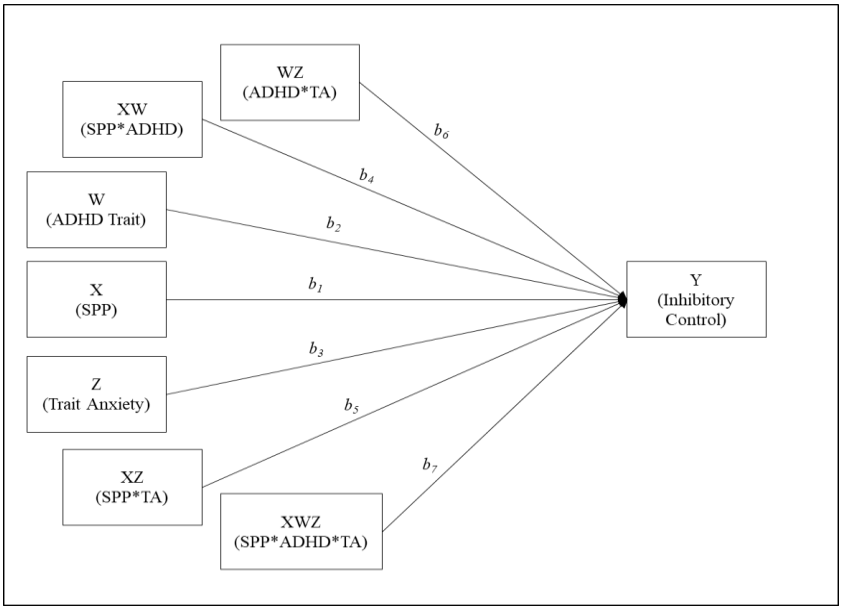


Figure 4

Statistical Model (PROCESS Model 3)



Note. Conditional effect of *X* on $Y = b_1 + b_4W + b_5Z + b_7WZ$ (Hayes, 2013).

Distractor AX-CPT Performance Measures and Descriptive Statistics

Task Performance

Hit Rates (HR) were calculated by counting how many times participants responded on Go trials and dividing this number by the overall number of trials. For total hit rate (HRT), the total number of responses was divided by 100 with the highest HR possible is 1. There was no significant difference between HR for distractor (*M*=.98, *SD*=.05) and no distractor (*M*=.98, *SD*=.03) conditions; *t*(59)=.708, *p*=.482. *False Alarm* (FA, commission errors) rates were calculated by the number of total responses on NoGo trials. There were 100 NoGo trials in total, 50 of which had distractors. On average, participants made few FAs (*M*=.67, *SD*=1.07); the maximum number of FAs was 4 and most participants (62%) made FA. Participants made significantly more FAs for distractor (*M*=.52, *SD*=.91) compared to no distractor conditions (*M*=.15, *SD*=.36); *t*(59)=3.22, *p*<.01 (Refer to Table 9 in Appendix A for the relationships between task performance and model variables). *Response Time* (RT) was calculated as an average response time for correctly answered Go trials (NoGo condition did not require a response). Participants showed a faster RT for distractor (*M*=314.17, *SD*= 56.48) compared to no distractor (*M*=360.16, *SD*=79.53) trials *t*(59)=-6.012, *p*<.001.

Comparison of N2 Amplitude across AX-CPT Conditions

A two-way repeated measures ANOVA was performed for Condition (Go vs. NoGo) and Trial (Distractor vs. No Distractor; See Table 4 for M and SD and Figure 5 for ERP waveforms). There was a significant main effect of Condition ($F(1,59)=18.95$, $p<.001$, $\eta_p^2=.243$). NoGo N2 amplitudes were significantly larger than Go N2 amplitudes regardless of the Trial type [$t(59)=4.13$, $p<0.001$, d=.053]. Trial main effect ($F(1,59)=.28$, $p=.59$, $\eta_p^2=.005$) and Condition X Trial interaction were not significant [$F(1,59)=.95$, $p=.33$, $\eta_p^2=.016$].

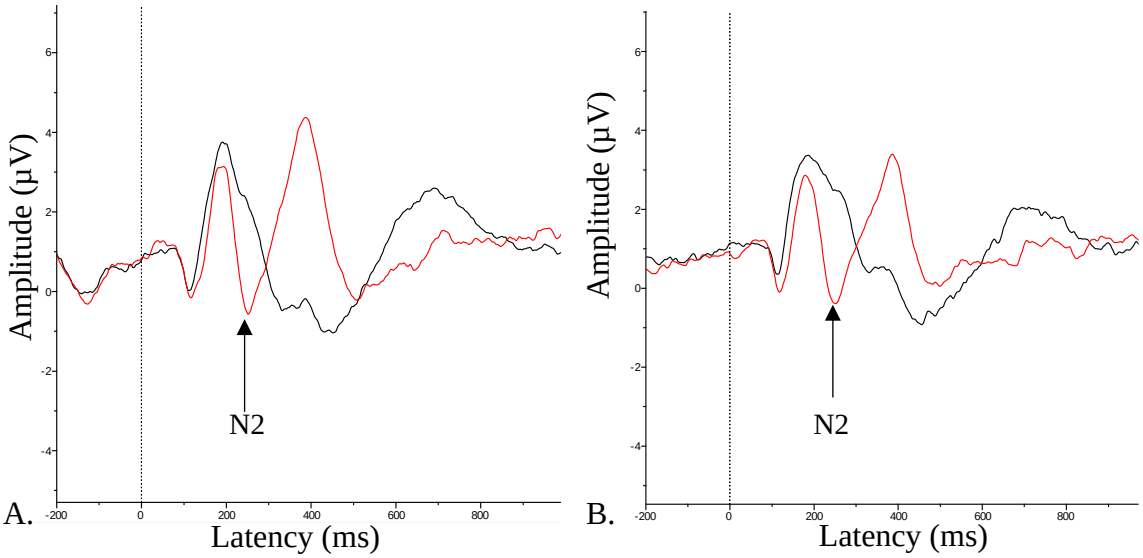
Table 4

Means and Standard Deviations of N2 Amplitudes(uV) and Latencies (ms)

	Amplitude (uV)		Latency (ms)	
Condition/Trial	***M***	***SD***	***M***	***SD***
Go				
Distractor	-2.42	2.60	271.77	33.04
No Distractor	-2.38	2.05	273.40	31.52
NoGo				
Distractor	-3.44	2.73	259.23	21.21
No Distractor	-3.73	2.45	256.90	23.86

Figure 5

N2 Waveforms for Distractor (A) and No Distractor (B) Trials for Electrode 7



Note. NoGo Trials are depicted in red and Go trials are depicted in black. Electrode 7 is located between Fz and FCz scalp electrodes in 128- electrode Geodesic Sensor Net.

Table 5

Correlations Between Predictor and Moderator Variables Used in the Analyses

	1.	2.	3.	4	5.	6.
1. Low Registration	-					
2. Sensory Sensitivity	.63**	-				
3. Inattention	.52**	.21	-			
4. Hyperactivity	.33*	.17	.50**	-		
5. Impulsivity	.47**	.29*	.65**	.67**	-	
6. Trait Anxiety	.55**	.42**	.445**	.11	.42**	-

*****p<0.05, **p<0.01

Table 6

Correlations Between Predictor and Moderator Variables and N2 Amplitude Conditions

	1.	2.	3.	4	5.	6.
Go Distractor	.08	.06	.25†	.11	.25†	.12
Go No Distractor	.08	.05	.03	-.09	-.02	.12
NoGo Distractor	-.18	-.07	.05	.15	.10	.02
NoGo No Distractor	-.24	-.17	-.08	.04	.01	.08

†p<0.08

Note. 1. Low Registration, 2. Sensory Sensitivity, 3. Inattention, 4. Hyperactivity, 5. Impulsivity, 6. Trait Anxiety.

Moderated Moderation Analyses

The results of the moderated moderation analyses for LR and SS were shown in the Appendix as Tables 7 and 8, respectively. N2 amplitude is a negative value, therefore a positive relationship between SPPs (LR & SS) and N2 amplitude means that higher SPP score is associated with a smaller N2 amplitude. Likewise, a negative relationship between SPP and N2 amplitude means that higher SPP scores is associated with larger N2 amplitudes. In the following

sections, first the significant 3-way interactions that include SPP*ADHD-traits*Trait Anxiety were reported. When the analyses did not yield significant 3-way interactions, but significant 2-way interactions observed between the predictor variable (SPP) and one of the moderators (either ADHD-traits or trait anxiety) these 2-way interactions were also analyzed in additive multiple moderation models. For the goals of this study, analysing significant 2-ways involving the moderators in the absence of the hypothesized 3-way interactions were important to understand the influence of SPPs on N2 amplitude because the additive model would account for the effect of each moderator independently**.**

Low Registration and Inhibitory Control

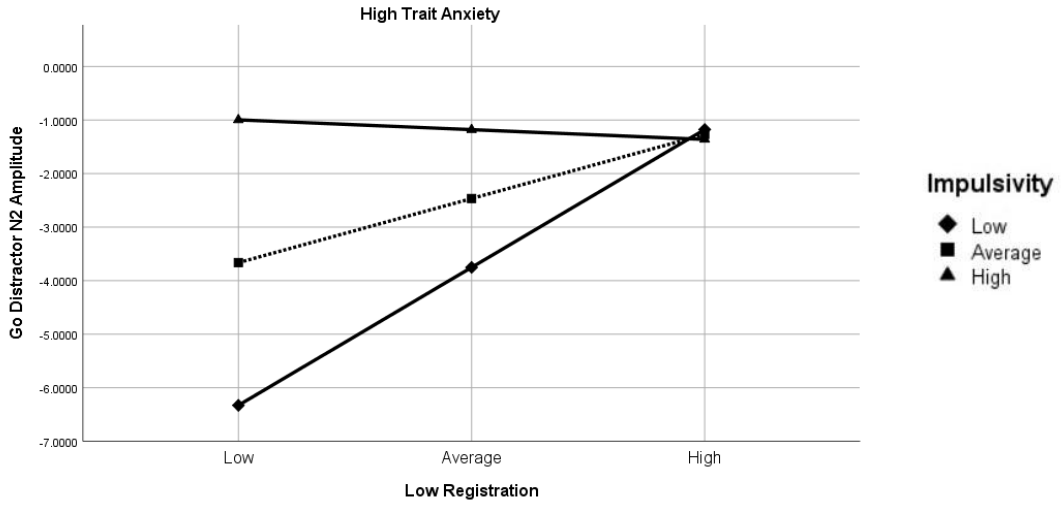
Hypothesis 1: The effect of low registration on inhibitory control(N2 amplitude) will be a function of the level of ADHD-traits (inattention, hyperactivity, impulsivity) and trait anxiety; therefore, a significant three-way interaction involving low registration, ADHD-traits and trait anxiety was hypothesized in all three inhibitory conditions.

Go Distractor (Cognitive Inhibition). Three separate moderated moderation models were tested using LR as focal predictor (X), N2 amplitude in Go Distractor as outcome (Y), ADHD-traits (W; inattention, hyperactivity, impulsivity) and trait anxiety (Z) as primary and secondary moderators, respectively. The models testing the effects of LR on N2 amplitude as a factor of inattention and trait anxiety and, hyperactivity and trait anxiety were not significant (See Table 7 Appendix A). The moderated moderation testing the effects of LR on N2 amplitude dependent on *impulsivity and trait anxiety* was statistically significant accounting for 23.5% of the variance in Go Distractor N2 amplitudes ($F(7,52)=2.28$, $p=.04$). There was a significant 3-way interaction of LR*trait anxiety*impulsivity ($b=-.002$, $t(52)=-2.40$, $p=.02$) (See Table 7 Appendix A). This interaction was probed by simple slope analyses, looking at how the

relationship between LR and N2 amplitude changed depending on the levels of impulsivity and trait anxiety (See Summary Table 10 in Appendix A). The results showed that only at the higher levels of trait anxiety the effect of LR on N2 amplitude was significantly moderated by impulsivity. In other words, LR was positively related to N2 amplitude (b=.35, t(52)=2.70, p<.01; smaller N2 amplitudes) when impulsivity is low and trait anxiety is high (See Figure 6).

Figure 6

Simple Slopes Analyses of Go Distractor N2 Amplitude for Low Registration



NoGo Distractor (Dual Inhibition). Three separate moderated moderation models were tested using LR as (X) N2 amplitude in NoGo Distractor (Y), and ADHD-traits (W; inattention, hyperactivity, impulsivity) and trait anxiety (Z) as moderators. The models testing the effects of LR on N2 amplitude as a factor of inattention and trait anxiety, and hyperactivity and trait anxiety were not significant (See Table 7 Appendix A). The moderated moderation testing the effects of LR on N2 amplitude as a factor of impulsivity and trait anxiety was not statistically significant (F(7, 52) =1.81, p=.11). There was a significant 3-way interaction LR*impulsivity*trait anxiety (b=-.002, t(52)=-2.03, p<.05) . This interaction was probed by

simple slope analyses, to understand how the relationship between LR and N2 amplitude changed depending on the level of impulsivity and trait anxiety (See Table 11 in Appendix A). The results of the simple slope analyses were not significant.

NoGo No Distractor (Response Inhibition). Three separate moderated moderation models were tested using LR as (X) N2 amplitude in NoGo No Distractor (Y), and ADHD-traits (W; inattention, hyperactivity, impulsivity) and trait anxiety (Z) as moderators.
The models testing the effects LR on N2 amplitude as a factor of inattention and trait anxiety, and hyperactivity and trait anxiety were not significant (see Table 7 in Appendix A). The overall model testing the effects of LR on N2 amplitude as a factor of impulsivity and trait anxiety was statistically significant, accounting for 27.0% of the variability in NoGo No Distractor N2 amplitude ($F(7,52)=2.75$, $p=.02$). The 3-way interaction between LR*impulsivity*trait anxiety was not significant ($b=-.002$, $t(52)=-1.94$, $p=.06$; See Table 1 in Appendix A).

Summary of the Low Registration Models

The hypothesized significant three-way interaction involving LR, ADHD-traits (inattention, hyperactivity and impulsivity) and trait anxiety predicting N2 amplitude was supported only in *Go Distractor* (Cognitive Inhibition) and NoGo Distractor (Dual Inhibition) conditions when ADHD-trait impulsivity was the primary moderator. However only in Go Distractor condition simple slope analyses of this significant interaction revealed meaningful moderator effects. Overall impulsivity moderates the effect of LR on N2 amplitude, and this effect was dependent on the level of trait anxiety. In other words, when the trait anxiety is high, individuals who were low in LR and low in impulsivity had larger N2 response, but individuals who were high in LR and high in trait anxiety had smaller N2 amplitude (See Figure 6).

Sensory Sensitivity and Inhibitory Control

Hypothesis 2: The effect of sensory sensitivity on inhibitory control (N2 amplitude) will be a function of the level of ADHD-traits (inattention, hyperactivity, impulsivity) and trait anxiety; therefore, a significant three way interaction involving sensory sensitivity, ADHD-traits and trait anxiety was hypothesized in all three inhibitory conditions.

Go Distractor (Cognitive Inhibition). Three separate moderated moderation models were tested using SS as the focal predictor (X) N2 amplitude in Go Distractor as the outcome (Y), and ADHD-traits (W; inattention, hyperactivity, impulsivity) and trait anxiety (Z) as primary and secondary moderators respectively. The models testing the effects SS on N2 amplitude as a factor of inattention and trait anxiety, and hyperactivity and trait anxiety were not significant (see Table 8 in Appendix A). The overall model testing the effects of SS on N2 amplitude as a factor of impulsivity and trait anxiety was statistically significant, accounting for 23.0% of the variability in Go Distractor N2 amplitude ($F(7,52)=2.22$, $p<.05$). There was a statistically significant 2-way interaction of SS*trait anxiety ($b=.01$, $t(52)=2.21$, $p=.03$) (See Table 7), but the 3-way interaction was not significant ($b=-.001$, $t(52)=-1.49$, $p=.14$). To further probe the significant interaction between SS*trait anxiety, an additive multiple moderation was conducted (PROCESS Model 2, see Figures 7 & 8, Refer Appendix A Table 12).

Figure 7

Conceptual Double Moderation Model (PROCESS Model 2)

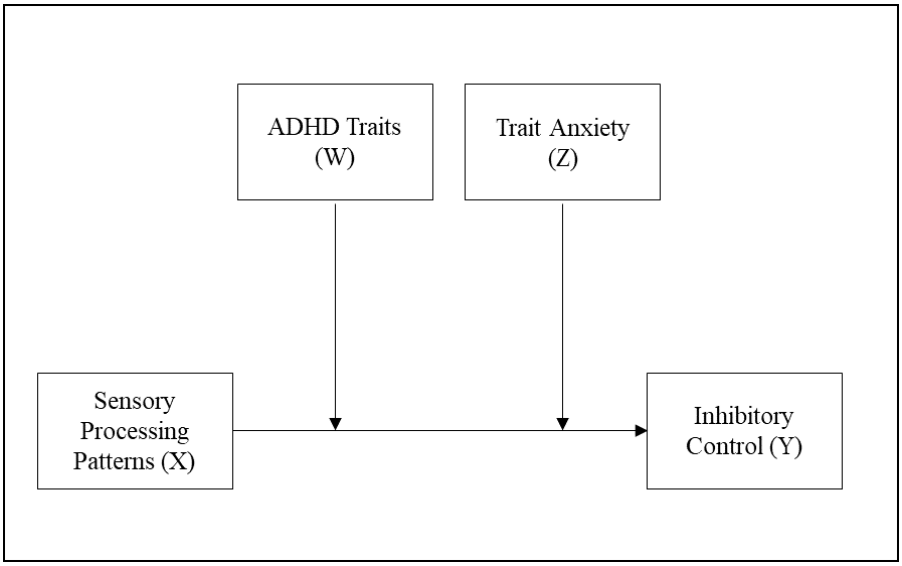
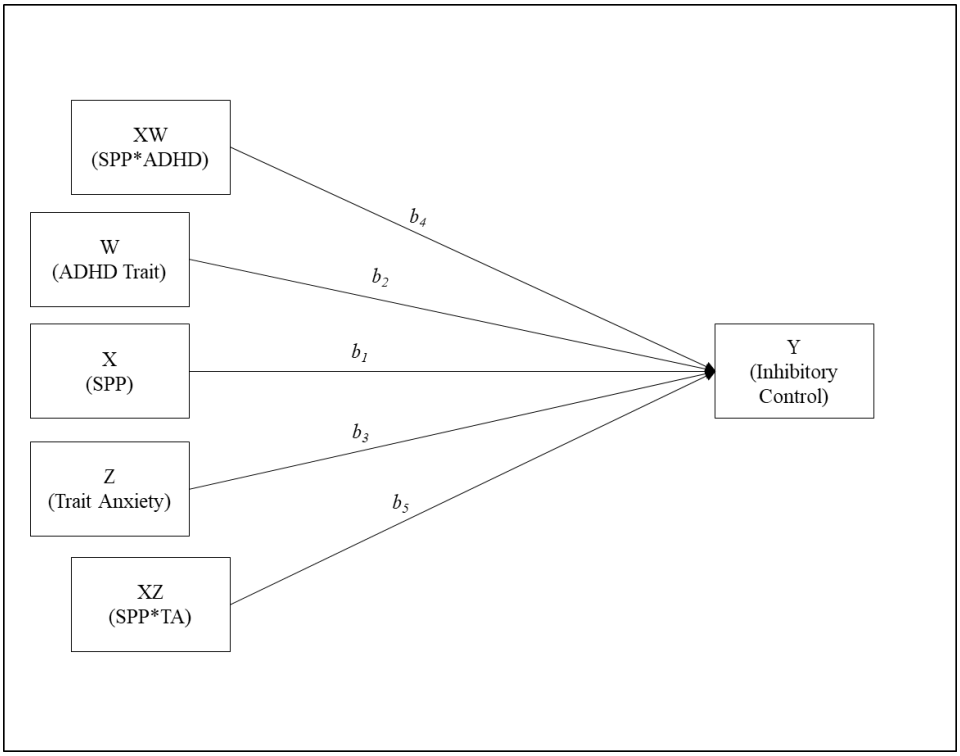


Figure 8

Statistical Double Moderation Model (PROCESS Model 2)

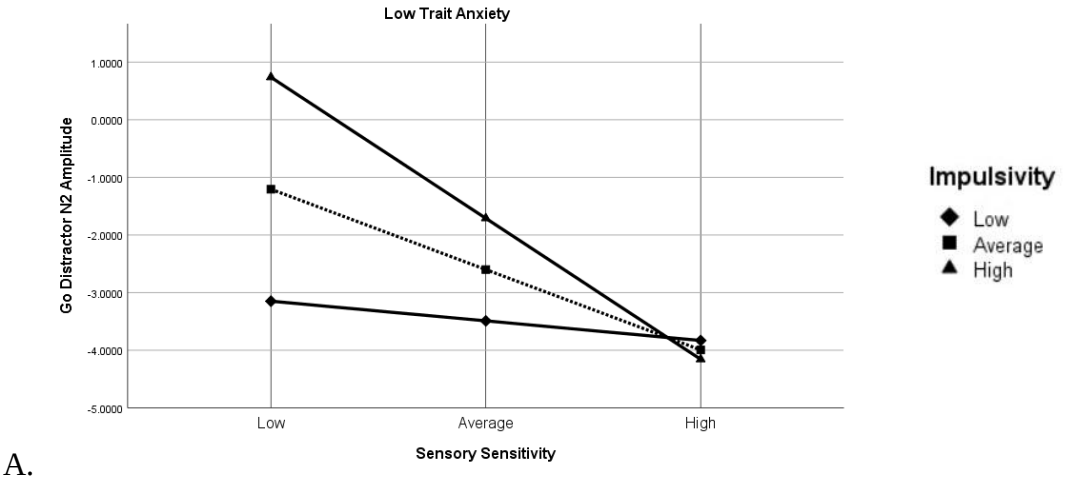


Note. Conditional effect of X on $Y = b_1 + b_4W + b_5Z$ (Hayes, 2013).

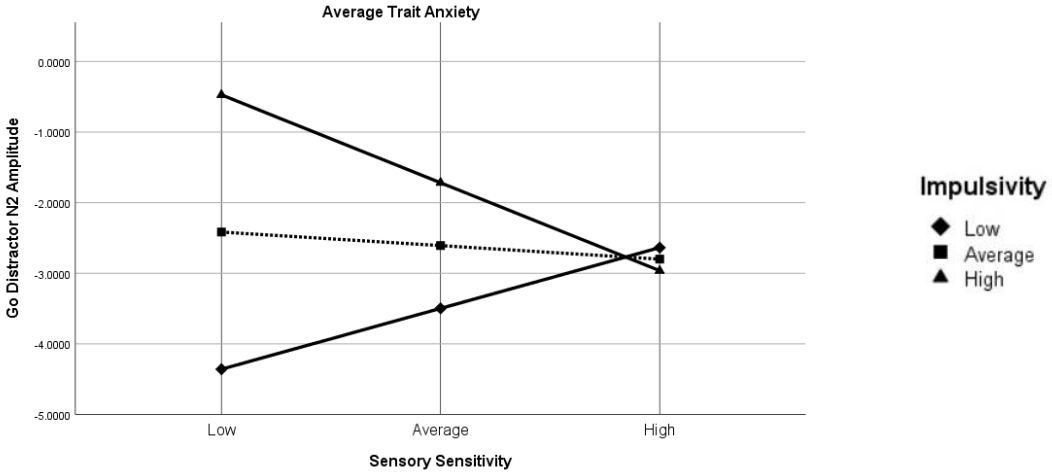
Additive Multiple Moderation. The overall model of SS on N2 amplitude as a factor of *impulsivity* and *trait anxiety* was statistically significant, accounting for 18.8% of the variability in Go Distractor N2 amplitude ($F(5,54)=2.49$, $p=.04$; see Table 12 in Appendix A). The analyses revealed 2 statistically significant 2-way interactions, SS*impulsivity ($b=-.03$, $t(54)=-2.64$, $p=.01$) and SS*trait anxiety ($b=.02$, $t(54)=2.73$, $p<.01$).These interactions were probed by simple slopes analyses, to understand how the relationship between SR and N2 amplitude changed as the levels of impulsivity and trait anxiety changed (See Table 13 in Appendix A for a summary). The results showed that SS was positively related to N2 amplitude ($b=.30$, $t(54)=2.35$, $p=.01$; i.e. smaller N2 amplitudes) in participants with low levels of impulsivity and high levels of trait anxiety (See Figure 9C). In contrast, SS was negatively related to N2 amplitude (i.e., larger N2 amplitudes) in those with high levels of impulsivity and average or low trait anxiety, ($b=-.18$, $t(54)=-2.15$, $p=.04$; $b=-.36$, $t(54)=-2.72$, $p<.01$; Figure 9A & B) and at average levels of impulsivity and low trait anxiety ($b=-.20$, $t(54)=-2.36$, $p=.02$; Figure 9A). By looking at the signs of the slopes and the magnitude of the effects, it is plausible to say that at different levels of impulsivity and trait anxiety both the strength and the direction of the effect of SS on N2 amplitude changed.

Figure 9

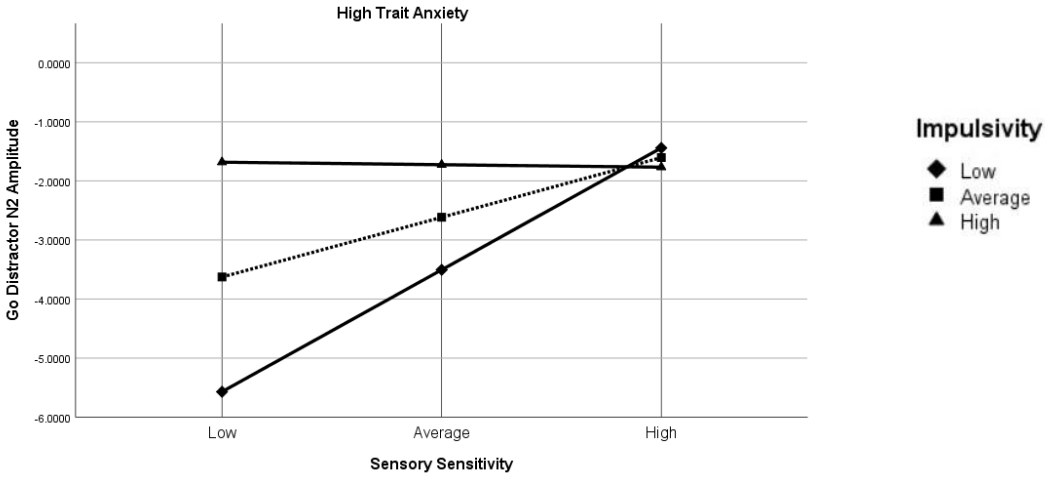
Simple Slopes Analyses for Go Distractor N2 Amplitude for Sensory Sensitivity



A.



B.

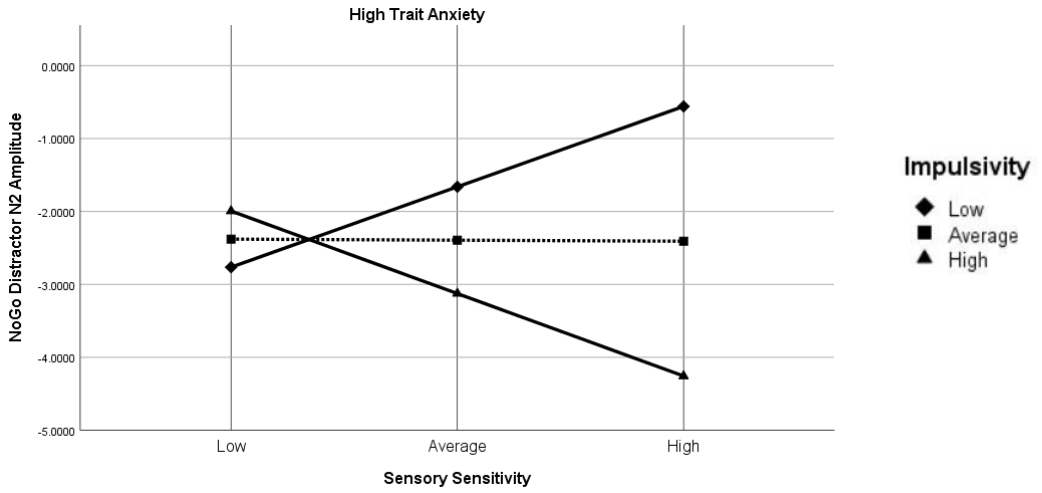


C.

NoGo Distractor Trials (Dual Inhibition). Three separate moderated moderation models were tested using SS as the focal predictor (X) N2 amplitude in NoGo Distractor as the outcome (Y), and ADHD-traits (W; inattention, hyperactivity, impulsivity) and trait anxiety (Z) as primary and secondary moderators respectively. The models testing the effects SS on N2 amplitude as a factor of inattention and trait anxiety, and hyperactivity and trait anxiety were not significant (See Table 14 Appendix A). The moderated moderation testing the effects of SS on N2 amplitude as a factor of *impulsivity and trait anxiety* was statistically significant accounting for 25.4% of the variability in NoGo Distractor N2 amplitude ($F(7,52)=2.53$, $p=.03$). The 3-way interaction of SS*impulsivity*trait anxiety was statistically significant ($b=-.003$, $t(52)=-3.04$, $p<0.01$), This interaction was probed by simple slopes analyses (See Table 14 in Appendix A). The results showed that SS was negatively related to N2 amplitude (i.e., smaller N2 amplitudes) in those with both high levels of impulsivity and high levels of trait anxiety, ($b=-.16$, $t(52)=-2.15$, $p=.04$; see Figure 10).

Figure 10

Simple Slopes Analyses for NoGo Distractor N2 Amplitude for Sensory Sensitivity



NoGo No Distractor Trials (Response Inhibition)

Three separate moderated moderation models were tested using SS as (X) N2 amplitude in NoGo No Distractor (Y), and ADHD-traits (W; inattention, hyperactivity, impulsivity) and trait anxiety (Z) as moderators.

The models testing the effects SS on N2 amplitude as a factor of inattention and trait anxiety, and hyperactivity and trait anxiety were not significant (see Table 5). The overall model testing the effects of SS on N2 amplitude as a factor of impulsivity and trait anxiety was statistically significant, accounting for 22.9% of the variability in NoGo No Distractor N2 amplitude ($F(7,52)=2.21$, $p<.05$). There was a statistically significant 2-way interaction of impulsivity*trait anxiety ($b= -.02$, $t(52)=-2.84$, $p<.01$) (See Table 8 in Appendix A) but the 3-way interaction was not significant and therefore the interaction was not probed further.

Summary of Sensory Sensitivity Models

Overall, the hypothesized significant three-way interaction involving SS, ADHD-traits (inattention, hyperactivity and impulsivity) and trait anxiety predicting N2 amplitude was supported only in NoGo Distractor condition (Dual Inhibition) when ADHD-trait impulsivity was the primary moderator. Specifically, at high levels of trait anxiety, individuals high in SS and high in impulsivity had larger N2 amplitudes (See Figure 10) but when impulsivity was low, smaller N2 amplitudes were obtained. These results suggest that the effect of SS on N2 amplitude is moderated by different levels of impulsivity (high versus low) at high levels of trait anxiety.

Three-way interaction for the Go Distractor condition was not significant but because SS*impulsivity and SS*trait anxiety interactions were significant and both of these moderator variables have been shown to co-occur with SS, their effects were probed further using an additive multiple moderation model (See Figure 9). The results indicated that the effect of SS on N2 amplitude was significant and positive in individuals with high trait anxiety and low impulsivity. In other words, high sensory sensitivity predicts smaller N2 amplitude. The effect of SS on N2 amplitude is significant and negative in individuals with low trait anxiety and high impulsivity. In other words, high sensory sensitivity predicts larger amplitude. Overall, in both conditions the direction and magnitude of the effect of SS on N2 amplitude changes depending on the level of trait anxiety and level of impulsivity.

Discussion

The findings of this study showed that impulsivity moderated the effect of two sensory processing patterns, LR and SS, on N2 amplitude, but this effect was also dependent on the level of trait anxiety. In general, the results suggest the importance of complex comorbid patterns because the co-existence of ADHD-trait impulsivity and trait anxiety influenced the neurophysiological response to inhibitory task demands, conceptualized as N2 amplitude. Specifically, the hypothesized significant three-way interaction involving LR, ADHD-traits (inattention, hyperactivity and impulsivity) and trait anxiety predicting N2 amplitude was supported in the *Go Distractor (Cognitive Inhibition)* and *NoGo Distractor (Dual Inhibition)* conditions when ADHD-trait impulsivity was the primary moderator. Similarly, the hypothesized three-way interaction involving SS, ADHD-traits (inattention, hyperactivity and impulsivity) and trait anxiety predicting N2 amplitude was supported in the *NoGo Distractor (Dual Inhibition)* condition when ADHD-trait impulsivity was the primary moderator. In the *Go Distractor (Cognitive Inhibition)* condition, two two-way interactions involving SS and impulsivity, and SS and trait anxiety were significant.

Overall, there is a partial support for hypotheses in the *Go Distractor* and *NoGo Distractor* conditions when impulsivity is the primary moderator of the focal effect. These results highlight the importance of examining the complex relationships among comorbid patterns that are frequently observed in diagnostic groups. They also lend support to the importance of including sensory processing in the Research Domain Criteria (RDoC) framework as a transdiagnostic mechanism and risk factor for mental health problems (Harrison et al., 2019; Hengartner & Lehmann, 2017). RDoC framework uses processes in affective, cognitive, social, arousal/regulatory and sensorimotor systems to understand underlying mental health and illness.

In this discussion the main findings were discussed in the context of the underlying traits in psychopathological conditions. It is important to clarify that the N2 amplitude was used as a neurophysiological correlate of inhibitory control, as it has been frequently used in clinical and non-clinical studies (Albrecht et al., 2005; Dimoska et al., 2003; Klymkiw et al., 2017). It should not be interpreted as a clinical marker to define any psychopathological conditions.

Main Findings

Low Registration

There were two significant three-way interactions involving LR, impulsivity and trait anxiety predicting N2 amplitude in Go Distractor (Cognitive Inhibition) and NoGo Distractor (Dual Inhibition) conditions. However, the simple slope analyses of these significant interactions revealed meaningful moderator effects in the Go Distractor condition only and so the NoGo Distractor results were not discussed further. The key finding for the LR was that impulsivity moderated the effect of LR on N2 amplitude, and this effect was dependent on the level of trait anxiety. In other words, *when trait anxiety was high, individuals who were low in both LR and impulsivity had a larger N2 response, but individuals who were high in both LR and trait anxiety but low in impulsivity had smaller N2 amplitude (See Figure 6).* When trait anxiety was low, the model did not predict N2 amplitude. The fact that this relationship was found for the Go Distractor Condition suggests that, anxiety is related to a larger response when inhibitory control was required, specifically cognitive inhibition demands which were indexed by the N2 in Go Distractor conditions. This result is consistent with the Attentional Control Theory (ACT, Eysenck et al., 2007). ACT suggests that individuals with anxiety exert more cognitive effort to maintain task performance when task demands become overwhelming especially due to interfering processes such as worry, a cognitive component of anxiety (Eysenck et al., 2007).

Although in this study worry was not measured directly, the STAI captures the worry component, for example in items such as “I worry too much over something that really does not matter” (Spielberger et al., p. 75). One explanation for larger N2 in Go Distractor condition may be that the individuals with high trait anxiety exert more inhibitory control to perform the task when there are distractors that should be ignored during the task. Another explanation may be the attentional bias that has been reported in individuals with high anxiety. It has been shown that individuals with trait anxiety have attentional bias to threatening (Cisler & Koster, 2010; Wieser & Keil, 2020) as well as non-threatening distractors (Fox, 1994; Gaspar & McDonald, 2018). As mentioned in the Method section (see p. 44), the distractors in the d-AX-CPT task were originally designed as pleasant and unpleasant line drawings. However, the post-task ratings of the distractors revealed that only a handful of these distractors were rated as unpleasant; therefore, in the analyses pleasant and unpleasant distractors were collapsed into “Distractor” trials. The Go Distractor condition in the d-AX-CPT is a simple target detection task that requires fast and accurate response while ignoring distractor line drawings (both pleasant and unpleasant). Therefore, the larger N2 amplitude that was observed in individuals with low LR (people who do not have problem for picking up the environmental stimuli) and low impulsivity (people who do not have urgency to act) when trait anxiety is high can be explained by the general tendency to engage in distractors as well as to inhibit these distractors in order accomplish the task correctly, the characteristics that have been frequently reported in people with high trait anxiety (Gaspar & McDonald, 2018).

On the other hand, individuals with high trait anxiety and high LR have a smaller N2 amplitude, suggesting a decrease in neurophysiological response to cognitive inhibition demands of the task. Individuals with high LR tend to miss stimuli that others may notice, which could in

part explain why there is a decrease in response (Dunn, 2002). Additionally, high scores in LR were significantly related to more omission errors, though it should be noted that there were ceiling effects in behavioural measures (See Table 9 in Appendix A). Engel-Yeger and Dunn (2011) suggested that individuals with high LR and anxiety might not notice the cues to which others respond and once they notice the cues, the sensation might be overwhelming to them. This pattern of a late attention to sensory cues, partly due to LR, and the feelings of increased responsivity to stimuli once they are detected, partly due to trait anxiety, may help to explain the reduced response to cognitive inhibition demands indexed by lower N2 amplitudes in this study (Engel-Yeger & Dunn, 2011). However, there is a possibility that this pattern of response could relate to more attention and panic leading to increased N2 amplitudes.

Sensory Sensitivity

There was one significant three-way interaction for SS, impulsivity and trait anxiety predicting N2 amplitude in NoGo Distractor condition (Dual Inhibition). In the NoGo Distractor condition of the d-AX-CPT two inhibitory processes were in effect. One was the classical response inhibition, not to respond to any letter other than X when they were preceded by A, and the other process was to ignore the distractor line drawings. The key finding was that the individuals with *high levels of SS, impulsivity and trait anxiety had larger N2 amplitudes, but when impulsivity was low and both trait anxiety and SS were high, smaller N2 amplitudes were obtained (See Figure 10).* These results suggest that the effect of SS on N2 amplitude was moderated by different levels of impulsivity (high versus low) at high levels of trait anxiety. Anxiety is often related to excessive engagement of the behavioural inhibition system (Epstein et al., 1993; Gray & McNaughton, 2000; Grillon et al., 2017; Quay, 1997; Sylwan, 2004). The effect of anxiety on N2 amplitude in Go/NoGo tasks has been mixed as some results suggest a

larger N2 (Hum et al., 2013; Righi et al., 2009), no difference in N2 amplitude (Yang & Li, 2014) and smaller amplitude (Xia et al., 2020). The results of this study provide valuable insight to these seemingly contradicting results as the findings revealed that all these different outcomes are possible in the presence of other risk factors, such as ADHD-traits and SPPs. Specifically, it could be that in some cases anxiety leads to increased focus and in others and distraction. In high SS and anxiety individuals, N2 amplitude is lower which could because these two hypervigilant regulatory styles lead to increased distraction. Most ADHD studies suggest that the NoGo N2 is smaller in those with ADHD (Albrecht et al., 2005; Dimoska et al., 2003; Johnstone et al., 2009; Liotti et al., 2007; 2010). One study looking at ADHD and anxiety suggests that NoGo N2 amplitude was larger in ADHD and anxious youth than ADHD only youth, which is similar to the findings of the present study (Klymkiw et al., 2017). Klymkiw and colleagues (2017) further suggested that youth with anxiety had fewer challenges with impulsivity (Manassis et al., 2000). Those results were discussed in light of ACT (Eysenck et al., 2007). As mentioned previously, according to ACT, performance is maintained by increased processing efficiency but if level of state anxiety is increased or the task demands are too high, performance can suffer in individuals with anxiety (Eysenck et al., 2007; Rodriguez et al., 2014). In individuals with ADHD and anxiety, the concern about performance due to anxiety may motivate and enhance performance during simple tasks (low levels of state anxiety), thus leading to better impulse control (Rodriguez et al., 2014). Therefore, anxiety and SS together may provide an attention enhancing effect in the context of high impulsivity.

In individuals with high SS and high trait anxiety but low impulsivity, N2 amplitude was decreased suggesting reduced neurophysiological response to cognitive inhibition demands. SS and anxiety are related to being more attentive and physiologically reactive to possible

threats/distractors in the environment and SS is related to increased state anxiety (Engel-Yeger & Dunn, 2011; Liss et al., 2005). As mentioned before, task performance is unaffected by anxiety when increased cognitive effort is employed, but when task demands become too high or state anxiety is high, task performance can suffer (Eysenck et al., 2007; Rodriguez et al., 2014). These individuals could have higher state anxiety which could overwhelm them impacting processing efficiency and task performance. These participants could also pay attention to the distractors and not to the task due to the increased response to threat in both anxiety and SS (Engel-Yeger & Dunn, 2011; Liss et al., 2005). In relation to the N2 studies mentioned, the results of this study provide evidence for both an increased and decreased N2 response in anxious individuals who were hypersensitive (high SS) depending on the level of impulsivity (low versus high). The results of these studies may differ due to experimental design, group studied (developmental and clinical status), or task demands. For example, Xia and colleagues (2020) found decreased N2 amplitude in highly trait anxious individuals and their task had increased demands due to using two pairs of stimuli. This is similar to this present study as we expected increased task demands due to distractors. Overall, these results suggest that the effect of SS on N2 amplitude is moderated by different levels of impulsivity (high versus low) at high levels of trait anxiety.

The three-way interaction for sensory sensitivity, impulsivity and trait anxiety was not significant in the Go Distractor condition; however, the SS and impulsivity, and SS and trait anxiety interactions were significant. As both these moderator variables have been shown to co-occur with SS, their effects were probed further using an additive multiple moderation model. *The results indicated that the effect of SS on N2 amplitude had an attenuating effect in individuals with high trait anxiety and low impulsivity. In other words, high SS predicts smaller N2 amplitude (See Figure 9).* Highly trait anxious and hypersensitive individuals showed a

smaller N2 amplitude, suggesting a reduced inhibition response. Both SS and trait anxiety are related to an attentional bias to threat. Research suggests there is overall lowered PFC control in hypersensitivity and anxiety due to difficulties in disengaging attention from threat (Cisler & Koster, 2010; Green et al., 2015) but also while performing a low demand non-threatening task (Bishop, 2009). There is no direct threat in this study; however, as stated before the distractors may have an attention capturing quality. Since cognitive inhibition requires participants not to attend to distractors, these individuals may have been attending to the distractors and not the task.

High SS and high impulsivity were related to a larger N2 amplitude, suggesting an increased response to cognitive inhibition demands of the task. One explanation for this is that the SS (similar to trait anxiety) may help an impulsive individual to pay more attention to threat/distractors and lead to an increased cognitive inhibition response. Impulsivity has been linked to less attention designated to warning signals (Soshi et al., 2015), but hypersensitivity has been related to an "over-inclusion" of irrelevant sounds into the focus of attention (Kisley et al., 2004) and an increased response to threat (Green et al., 2015). However, when SS was low and impulsivity was high N2 amplitude was smaller, suggesting a decrease in neurophysiological response to cognitive inhibition demands of the task. In this case impulsive individuals may not be attending to the warning signals. Overall, at high levels of anxiety and low levels of impulsivity, SS showed a dampening effect on N2 amplitude in Go Distractor conditions.

Impulsivity & Anxiety

Overall, in all of the models the direction and magnitude of the effect of SPPs on N2 amplitude changed depending on the level of trait anxiety and level of impulsivity. Research has indicated a unique relationship between impulsivity and anxiety. For example, clinical studies

have shown that higher rates of impulsivity have been found in patients with a comorbid anxiety disorder compared to patients without an anxiety disorder or controls (Del Carlo et al., 2012; Taylor et al., 2008). Impulsivity and trait anxiety are related to the Behavioural Activation System (BAS) and Behavioural Inhibition System (BIS), respectively (Gray, 1987). Corr (2002) found that high anxiety strengthened affective reactions (electromyographic) when unpleasant slides were present in a visual task, but this effect was stronger in low impulsive individuals. Additionally, low anxiety and high impulsive participants showed the lowest avoidance of punishment to incorrect responses when arousal was augmented. Overall, this provided evidence to the Joint Subsystems hypothesis as the BIS and BAS together seem to influence behaviour. The Joint Subsystems hypothesis suggests that the BIS and BAS have the potential to influence both reward-mediated and punishment-mediated behaviour. In an ERP study using N1 as a neurophysiological response to measure selective attention and attention processing for goal-directed actions during a delay discounting task (Xia et al., 2017), it was found that the high trait anxious individuals were impulsive decision makers and they had larger N1 amplitude in immediate-option trials compared the low trait anxious individuals (Xia et al., 2017)

Inattention and hyperactivity were not significant moderators in any of the models. It is important to note that higher scores in impulsivity were related to higher SS and LR scores, but high hyperactivity and inattention were only related to high LR scores (See Table 5). Most studies examining ADHD look at the disorder, and not at the different types of ADHD or each individual trait. A lot of the studies above were measuring impulsivity as a trait, and not a symptom of ADHD. There has been some literature looking at inattention and anxiety, for example, Sluggish Cognitive Tempo (SCT). SCT is characterized by inconsistent alertness and

orientation (drowsiness, apparent daydreaming) (McBurnett et al., 2001) and is associated with inattention but only when hyperactivity-impulsivity is not present.

Implications

As mentioned previously, the RDoC framework uses a dimensional approach that allows for the examination of complex patterns of comorbidities (Harrison et al., 2019). This framework uses processes in affective, cognitive, social, arousal/regulatory and sensorimotor systems underlying mental health and illness. This study lends support to the idea that there should be a sensory processing dimension to the RDoC framework, as sensory processing acts as a transdiagnostic mechanism and vulnerability factor affecting cognitive performance (Harrison et al., 2019). The results of this study demonstrate the importance of understanding the complex relationship among comorbid patterns that are frequently observed in diagnostic groups, as the three-way interactions predicted inhibitory control and not each construct individually. These relationships are complex as the levels of each trait differentially affected each condition type. This study adds new information to the existing literature on the relationship between SPPs, ADHD and anxiety using a dimensional framework, and stresses their impact on cognitive functioning. There are no known studies that look at all these factors; however, there is a well-established link between cognitive functioning and anxiety and ADHD. As this is not a clinical sample, it is important to point out that high levels of these traits can lead to changes in cognitive function, which provides support to the range of severity for mental health problems. For example, individuals with extremely high anxiety may show more impacted cognitive performance than those who just reach the criteria for an anxiety disorder.

Limitations and Future Directions

Sample

The final sample consisted of 60 participants, with almost equal numbers of males and females. Although medium to larger effect sizes were observed in significant models with 3-way interactions [2] it is still important to consider these results as preliminary since small samples can produce statistically significant results because of outliers, although maintaining outliers did not change model outcomes. It is important to keep in mind that this is not a clinical group. In the future this study should be replicated with adolescents or preteens, using either a larger community and/or well-defined clinical samples. A university population is not ideal for understanding the effects of ADHD and anxiety as many of them have likely learned to mask their symptoms if they do have diagnoses for these disorders.

Task

The outcome variable, N2 amplitude, may not have captured the full range of variance in each predictor trait, due to the observed ceiling effect (little variation in hit rates, false alarms and reactions times, See Table 9 in Appendix), and also the failure to create a robust distractor effect in the paradigm, which all together could have reduced the power of hypothesized predictions. When looking at the N2 amplitudes and latencies (independent of SPPs, trait anxiety and ADHD traits) there were no significant differences by trial type (Distractor vs. No Distractor). When the control condition (Go No Distractor) was analysed using the moderated moderations, there was a significant 3-way interaction of low registration, impulsivity and trait anxiety (See Table 7). On the other hand, there was no significant 3-way interactions between

[2] Go Distractor for Low Registration (f^2=.31, observed power=.85) and NoGo Distractor for Sensory Sensitivity (f^2=.34; observed power=.89)

SS, ADHD-traits, and trait anxiety in the Go No Distractor Condition (See Table 8). The results for Go Distractor and Go No Distractor were similar when LR was a focal predictor but not when SS was a focal predictor. These results may suggest that there is a continuous inhibition occurring throughout the whole task, as participants had to continuously filter out distractors. Alternatively, these results could suggest that this 3-way interaction influences processing in general and not specifically inhibition, since there was no difference between groups. It is important to note that response time was significantly faster on Distractor compared to No Distractor trials, this may suggest that the distractors may act as cues for increased attention on certain trials as they are only found in Go and NoGo conditions and not throughout the task (i.e., Nontarget Condition). To possibly eliminate the impact of distractors as a source of continuous inhibition or a cue to participants, they should be embedded throughout the entire task. Another possible explanation is that since the Go Condition does not have a clearly defined N2 component and the value may just reflect the most negative value within the allotted timeframe but not a true peak. In sum, future studies using this paradigm should examine the distractor effects by including the distractors throughout the task.

Some distractors were not rated as unpleasant as expected. The differences in distractor types were not discussed in detail in this thesis, it is important to note that 50 of the distractors were meant to be threatening/unpleasant, and 50 were meant to be pleasant/neutral. However, only 13 images were rated as unpleasant by 75% of people and 29 images were rated as unpleasant by 65% of people. The low number of unpleasant trials prevented investigating the effects of "threat versus non-threat" stimuli on N2 amplitude. This could be a confounding factor as trait anxious individuals may have been more strongly affected by the unpleasant distractors than the neutral/pleasant distractors. The future studies can utilize stimuli from a normalized

affective picture database such as International Affective Picture System (IAPS, Bradley & Lang, 2007) or normalize this database.

Self-report measures

Self-report measures were used for both ADHD-traits and trait anxiety, although self-reports include a participant's subjective view and can be biased (e.g., social desirability) (Rosenman et al., 2011). In addition, this study employed only one measure of inhibitory control. Future research could include other measures of inhibitory control to study the effects on N2. For sensory processing patterns, there are physiological measures that may be better at measuring a neurological threshold than the self-report Adult Adolescent Sensory Profile (AASP). For example, skin conductance can be used as a physiological measure (Brown et al., 2001). In this thesis there were some possible issues that arose with the validity of the sensory processing measures. There was a strong positive correlation between LR and SS ($r(58)=.63$, $p<.01$). These two patterns share a passive behavioural strategy, but they differ in terms of neurological thresholds (LR-high; SS-low). This positive relationship between LR and SS was also found in a larger sample (Tekok-Kilic, Frijters, Gordon, Thorne, & Segalowitz, manuscript in preparation). One explanation is that the AASP may not be properly capturing the different neurological thresholds. Metz and colleagues (2019) examined the behavioural response and threshold axes of Dunn's model on healthy adults. They found the behavioural response axis may not be reflecting a construct with ordinal range, which suggests that these behavioural response patterns may not reflect a response of characteristic styles. There could be a distortion in scores on the axis as the quadrant scores may reflect individuals' most common response strategies, but across settings, they may use different strategies (Metz et al., 2019). They found that the neurological threshold axis of Dunn's model reflected sensory processing patterns on a spectrum from low to high and

may represent an ordinal range. They suggested that perhaps the threshold is a personal, endogenous characteristic that stays consistent, unlike behavioural strategies. The sample size in this study (N=60) was not sufficient to conduct a factor analysis to test if these results are consistent with the results reported by Metz and colleagues (2019). On the other hand, as the results of this study showed that the high scores in SS were significantly related to higher scores in LR it was important to investigate the unique variance of LR and SS (focal predictors) in their effects. To investigate the possibility of shared variance of the focal predictors moderated moderation models including the second SPP of a covariate was re-calculated (for example SS was the covariate in LR analyses) but the results did not change indicating that LR and SS are uniquely predicting inhibitory control (N2 amplitude) in their own models. Due to Metz and colleagues (2019) comments about the inconsistency in the behavioural response measurement and the consistent response in the neurological threshold and the unexpected correlation between SS and LR, future studies should include all 4 quadrants. Additionally, in conjunction with the self-report measures, other physiological measures such as pupillometry and skin conductance could be used in order to measure sensory thresholds.

Sex differences

This sample had an almost even number of females and males; however, the sample size was still considered to be small to consider sex differences in these complex models. Research suggests that females are more likely to have high trait anxiety than males (Franklin et al., 2018), whereas more males are likely to rate higher in attentional difficulties (Panevska et al., 2014). Additionally, females have been reported to have more sensory processing abnormalities than males (Engel-Yeger, 2012). There have also been sex differences in CPT performance with ADHD and comorbid anxiety. For example, Newcorn and colleagues (2001) that the girls were

less impaired than boys on most ratings and many CPT measures, specifically on impulsivity, and girls with comorbid ADHD and anxiety made less CPT impulsivity errors than girls with ADHD only. Therefore, sex may also change the direction and magnitude of the effects that are observed in this study and future studies should consider including sex as another variable.

Conclusion

Overall, this thesis emphasizes that the psychopathological conditions do not always act in isolation, but instead transdiagnostic vulnerability factors (i.e., sensory processing) and multiple psychopathologies, (i.e., comorbid ADHD and anxiety), can interact leading to changes in cognition that would not exist in each disorder alone. Specifically, impulsivity moderated the effect of two sensory processing patterns, LR and SS, on N2 amplitude (our index of inhibitory control), but this was also dependent on the level of impulsivity and trait anxiety. The results of this thesis offer compelling evidence that SPP is a transdiagnostic factor affecting cognitive outcomes depends on a person's levels of impulsivity and trait anxiety. In this study, only the ADHD trait of impulsivity and not of inattention and hyperactivity were significant moderators, which may suggest a unique relationship between impulsivity and anxiety in relation to LR and SS. The findings of this study first, highlight the importance of understanding the complex relationships among comorbid patterns that are often found in diagnostic groups. Second, they add new information to the existing literature on the relationship between SPPs, ADHD and anxiety using a dimensional framework. Third, these findings suggest that complex comorbidities affect cognitive functioning, as indexed by the N2. This study examined a non-clinical sample of emerging adults, as this age group often show high rates of psychopathology, but these findings should be replicated in clinically diagnosed individuals in different age groups and physiological measures of sensory processing should be employed. The results of this study

and the idea of considering comorbidities and using a dimensional approach may help to explain inconsistent findings in the literature (i.e., effect of anxiety on NoGo N2 amplitude). Additionally, comorbidities and transdiagnostic factors can inform better treatment. For example, an individual with anxiety and high sensory sensitivity may respond well to treatment targeting behavioural strategies to make them comfortable in their environment.

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Appendix A

Table 7

Moderated moderation results with N2 amplitude as dependent variables and low registration as the predictor, with ADHD trait (3 types) moderation, and with trait anxiety moderating the moderator

	Dependent Variables											
	Go Distractor Amplitude			*Go No Distractor Amplitude*			*NoGo Distractor Amplitude*			*NoGo No Distractor Amplitude*		
	b	*se*	*CI*	*b*	*se*	*CI*	*b*	*se*	*CI*	*b*	*se*	*CI*
Inattention models												
Low Registration (X)	-0.01	0.07	[-0.14, 0.12]	0.03	0.05	[-0.07, 0.14]	-0.12	0.07	[-0.26, 0.02]	-0.11	0.06	[-0.23, 0.02]
Inattention (W)	0.17*	0.01	[0.01, 0.32]	-0.01	0.01	[-0.13, 0.11]	0.06	0.08	[-0.11, 0.22]	0.02	0.07	[-0.13, 0.16]
Trait Anxiety (Z)	0.03	0.04	[-0.06, 0.12]	0.04	0.03	[-0.03, 0.11]	0.03	0.05	[-0.07, 0.13]	0.09*	0.04	[0.01, 0.17]
LR*In	-0.01	0.01	[-0.03, 0.01]	-0.01	0.00	[-0.03, 0.01]	0.00	0.01	[-0.02, 0.03]	0.00	0.01	[-0.02, 0.02]
LR*TA	0.00	0.08	[-0.01, 0.02]	-0.01	0.00	[-0.02, 0.00]	-0.00	0.01	[-0.02, 0.01]	-0.00	0.01	[-0.02, 0.01]
In*TA	0.01	0.01	[-0.01, 0.02]	0.01	0.01	[-0.01, 0.02]	-0.00	0.01	[-0.02, 0.02]	-0.00	0.00	[-0.02, 0.01]
LR*In*TA	-0.001	0.00	[-0.00, 0.00]	-0.001	0.00	[-0.00, 0.00]	0.000	0.00	[-0.00, 0.00]	-0.001	0.00	[-0.00, 0.00]
	R^2 = .12			R^2 =.16			R^2 = .08			R^2 = .16		
Hyperactivity models												
Low Registration (X)	-0.02	0.06	[-0.14, 0.11]	0.03	0.05	[-0.06, 0.13]	-0.13*	0.07	[-0.26, -0.00]	-0.13*	0.06	[-0.23, -0.02]
Hyperactivity (W)	0.08	0.06	[-0.05, 0.20]	-0.03	0.05	[-0.12, 0.06]	0.11	0.07	[-0.02, 0.24]	0.09	0.06	[-0.02, 0.20]
Trait Anxiety (Z)	0.07	0.05	[-0.02, 0.03]	0.04	0.04	[-0.03, 0.11]	0.06	0.05	[-0.04, 0.15]	0.07	0.04	[-0.01, 0.15]
LR*Hyp	-0.01	0.01	[-0.03, 0.01]	-0.01	0.01	[-0.02, 0.00]	0.00	0.01	[-0.01, 0.02]	0.00	0.01	[-0.01, 0.02]
LR*TA	-0.00	0.01	[-0.01, 0.01]	-0.01*	0.00	[-0.02, -0.00]	-0.00	0.01	[-0.02, 0.01]	-0.00	0.00	[-0.01, 0.01]
Hyp*TA	0.01	0.01	[-0.00, 0.03]	0.01	0.01	[-0.01, 0,.02]	0.00	0.01	[-0.02, 0.02]	-0.01	0.01	[-0.02, 0.01]
LR*Hyp*TA	-0.001	0.00	[-0.00, 0.00]	-0.000	0.00	[-0.00, 0.00]	-0.000	0.00	[-0.00, 0.00]	-0.001	0.00	[-0.00, 0.00]
	R^2 = .09			R^2 =. 17			R^2 = .12			R^2 = .21†		
Impulsivity models												
Low Registration (X)	0.06	0.06	[-0.06, 0.18]	0.09†	0.05	[-0.00, 0.19]	-0.05	.066	[-0.18, 0.09]	-0.08	0.06	[-0.20, 0.03]
Impulsivity (W)	0.27*	0.08	[0.10, 0.43]	0.04	0.06	[-0.00, 0.18]	0.21	.09	[0.03, 0.39]	0.13	0.08	[-0.20, 0.03]
Trait Anxiety (Z)	0.01	0.04	[-0.08, 0.09]	0.04	0.03	[-0.03, 0.10]	0.03	.044	[-0.06, 0.12]	0.06	0.04	[-0.01, 0.14]
LR*Imp	-0.01	0.01	[-0.04, 0.01]	-0.01	0.01	[-0.03, 0.00]	-0.00	.01	[-0.03, 0.02]	0.00	0.01	[-0.02, 0.02]
LR*TA	0.01	0.01	[-0.00, .002]	-0.01	0.00	[-0.02, 0.10]	0.00	.01	[-0.01, 0.02]	0.00	0.01	[-0.01, 0.01]
Imp*TA	-0.00	0.01	[-0.02, 0.02]	0.01	0.01	[-0.00, 0.03]	-0.01	.01	[-0.03, 0.02]	-0.01	0.01	[-0.03, 0.01]
LR*Imp*TA	**-0.002***	0.00	[-0.00, -0.00]	**-0.002***	0.00	[-0.00, -0.00]	**-0.002***	.00	[-0.00, 0.00]	-0.002†	0.00	[-0.00, 0.00]
	R^2* = .23			***R^2* = .27***			R^2 = .20			***R^2*=.27***		

Note. †p<0.08, *p<0.05

Table 8

Moderated moderation results with N2 amplitude as dependent variables and sensory sensitivity as the predictor, with ADHD trait (3 types) moderation, and with trait anxiety moderating the moderator

	Dependent Variables											
	Go Distractor Amplitude			*Go No Distractor Amplitude*			*NoGo Distractor Amplitude*			*NoGo No Distractor Amplitude*		
	b	*se*	*CI*	*b*	*se*	*CI*	*b*	*se*	*CI*	*b*	*se*	*CI*
Inattention models												
Sensory Sensitivity (X)	0.03	0.06	[-0.09, 01.6]	0.03	0.05	[-0.07, 0.13]	0.00	0.07	[-0.13, 0.13]	-0.08	0.06	[-0.20, 0.03]
Inattention (W)	0.15*	0.07	[0.01, 0.29]	0.01	0.06	[-0.11, 0.11]	0.04	0.07	[-0.07, 0.11]	-0.06	0.07	[-0.19, 0.08]
Trait Anxiety (Z)	0.01	0.04	[-0.07, 0.09]	0.04	0.03	[-0.03, 0.10]	0.01	0.04	[-0.07, 0.13]	0.06	0.04	[-0.01, 0.14]
SS*In	-0.01	0.01	[-0.03, 0.02]	0.01	0.01	[-0.01, 0.03]	0.01	0.01	[-0.02, 0.03]	0.01	0.01	[-0.02, 0.00]
SS*TA	0.00	0.01	[-0.01, 0.01]	-0.00	0.00	[-0.01, 0.00]	-0.01†	0.01	[-0.02, 0.00]	-0.00	0.01	[-0.01, 0.01]
In*TA	-0.00	0.01	[-0.01, 0.01]	-0.01	0.01	[-0.02, 0.00]	-0.01	0.01	[-0.02, 0.01]	-0.01	0.01	[-0.02, 0.00]
SS*In*TA	-0.002	0.00	[-0.00,0.00]	-0.001	0.00	[-0.00, 0.00]	-0.002	0.00	[-0.00, 0.00]	-0.000	0.00	[-0.00, 0.00]
	R^2 = .14			R^2 =.08			R^2 = .09			R^2 = .11		
Hyperactivity models												
Sensory Sensitivity (X)	-0.00	0.06	[-0.11, 0.11]	0.00	0.05	[-0.09, 0.10]	-0.04	0.06	[-0.16, 0.08]	-0.07	0.05	[-0.17, 0.03]
Hyperactivity (W)	0.05	0.05	[-0.06, 0.16]	-0.03	0.04	[-0.12, 0.05]	0.08	0.06	[-0.04, 0.19]	0.03	0.05	[-0.06, 0.13]
Trait Anxiety (Z)	0.05	0.04	[-0.04, 0.13]	0.02	0.03	[-0.05, 0.08]	-0.00	0.04	[-0.09, 0.09]	0.01	0.04	[-0.06, 0.09]
SS*Hyp	-0.00	0.01	[-0.02, 0.01]	0.00	0.01	[-0.01, 0.02]	0.00	0.01	[-0.02, 0.02]	0.00	0.01	[-0.01, 0.02]
SS*TA	0.00	0.01	[-0.01, 0.01]	-0.00	0.00	[-0.01, 0.01]	-0.01	0.01	[-0.02, 0.00]	-0.00	0.04	[-0.01, 0.01]
Hyp*TA	0.01	0.01	[-0.01, 0.02]	-0.00	0.01	[-0.01, 0.01]	-0.00	0.01	[-0.02, 0.01]	-0.01†	0.01	[-0.02, 0.00]
SS*Hyp*TA	-0.000	0.00	[-0.00, 0.00]	0.000	0.00	[-0.00, 0.00]	-0.001	0.00	[-0.00, 0.00]	-0.001	0.00	[-0.00, 0.00]
	R^2 = .07			R^2 =.03			R^2 = .08			R^2 = .14		
Impulsivity models												
Sensory Sensitivity (X)	0.02	0.06	[-0.11,0.15]	0.05	0.05	[-0.06, 0.16]	0.05	0.07	[-0.09,0.18]	-0.06	0.06	[-0.18, 0.06]
Impulsivity (W)	0.21**	0.07	[0.06, 0.36]	0.02	0.06	[-0.11, 0.15]	0.15†	0.08	[-0.00, 0.31]	0.07	0.01	[-0.07, 0.21]
Trait Anxiety (Z)	-0.01	0.04	[-0.08, 0.07]	0.02	0.03	[-0.04, 0.08]	-0.01	0.04	[-0.09, 0.06]	0.03	0.03	[-0.04, 0.10]
SS*Imp	-0.02†	0.01	[-0.05, 0.00]	-0.01	0.01	[-0.03, .002]	-0.01	0.01	[-0.04, 0.02]	-0.00	0.01	[-0.02, 0.02]
SS*TA	0.01*	0.01	[0.00, 0.03]	0.00	0.01	[-0.01, 0.01]	-0.00	0.04	[-0.02, 0.01]	0.00	0.01	[-0.01, 0.01]
Imp*TA	-0.01	0.01	[-0.02, 0.01]	-.001	0.01	[-0.02, 0.00]	-0.01	0.01	[-0.03, 0.00]	-0.02**	0.01	[-0.03, -0.01]
SS*Imp*TA	-0.001	0.00	[-0.00, 0.00]	-0.001†	0.00	[-0.00, 0.00]	**-0.003****	0.00	[-0.00, -0.00]	-0.001	0.00	[-0.00, 0.00]
	R²* = .23			R^2 = .13			***R²* = .25***			***R²*=.23***		

Note. †p<0.08, *p<0.05

Table 9

Zero Order Correlations for Behavioural Results

	HR	HR ND	HR D	FA	FA D	FA ND
Low Registration	-.293*	-.181	-.282*	-.041	-.005	-.109
Sensory Sensitivity	-.248 †	-.097	-.253†	-.020	.019	-.108
Inattention	-.108	-.123	-.064	.236†	.276*	.001
Hyperactivity	-.108	-.221	-.009	.285*	.354**	-.050
Impulsivity	-.068	-.168	.010	.328*	.387**	-.008
Trait Anxiety	-.194	-.088	-.191	-.004	.019	-.061

Note. †p<0.08, ***p*<0.05, ****p*<0.01

Table 10

Summary of Simple Slopes Analysis of Go Distractor N2 amplitude

Impulsivity	Trait Anxiety	Prediction ability of Low Registration on N2 amplitude
High	High	ns (b=-.02, p=.76)
High	Average	ns (b=-.01, p=.89)
High	Low	ns (b= .00, p=.99)
Average	High	marginally significant (b=.16, p=.07)
Average	Average	ns (b=.06, p=.33)
Average	Low	ns (b=-.04, p=.66)
Low	High	significant (b=.34, p=.01*)
Low	Average	ns (b=.13, p=.12)
Low	Low	ns (b=-.08, p=.35)

Note. †p<0.08, ***p*<0.05, ****p*<0.01

Table 11

Summary of Simple Slopes Analysis of NoGo Distractor N2 amplitude

Impulsivity	Trait Anxiety	Prediction ability of Low Registration on N2 amplitude
High	High	Marginally significant (b=-.15, p=.08)
High	Average	ns (b=-.07, p=.46)
High	Low	ns (b= .02, p=.90)
Average	High	ns (b=-.03, p=.76)
Average	Average	ns (b=.05, p=.49)
Average	Low	ns (b=-.06, p=.52)
Low	High	ns (b=.10, p=.49)
Low	Average	ns (b=-.03, p=.77)
Low	Low	ns (b=-.15, p=.13)

Note. †p<0.08, ***p*<0.05, ****p*<0.01

Table 12

Double moderation results with Go Distractor N2 amplitude as the dependent variable and sensory sensitivity as the predictor, with impulsivity and trait anxiety as moderators.

Variables	b	se	95% CIs
Sensory Sensitivity	-0.028	0.05	[-0.13, -.08]
Impulsivity	0.18*	0.07	[0.03, 0.32]
Trait Anxiety	-0.00	0.04	[-0.07, 0.07]
Sensory Sensitivity x Impulsivity	-0.03*	0.01	[-0.05, -0.01]
Sensory Sensitivity x Trait Anxiety	0.02**	0.01	[0.00, 0.03]

Note. *p<.05, **p<.01. N=60. Since both the X*W and X*Z interactions are conditional on the third "missing" variable being set to 0 when X*W*Z is in the model, the 2-way interaction may not be meaningful on its own (Hayes, personal communication, 2020). Therefore, Model 2 was utilized to test whether this interaction was significant. Model 2 does not test the 3-way interaction, and in the case of the SS*trait anxiety interaction, impulsivity does not need to be set to 0.

Table 13

Summary of Simple Slopes Analysis of Go Distractor N2 amplitude (Model 2)

Impulsivity	Trait Anxiety	Prediction ability of SS on N2 amplitude
High	High	ns (b=-.01, p=.93)
High	Average	significant (b=-.18*, p=.04)
High	Low	significant (b=-.36**, p<.01)
Average	High	marginally significant (b=.15, p=.07)
Average	Average	ns (b=-.03, p=.60)
Average	Low	significant (b=-.20*, p=.02)
Low	High	significant (b=.30*, p=.01)
Low	Average	marginally significant (b=.13, p=.09)
Low	Low	ns (b=-.05, p=.46)

Note. *p<.05, **p<.01. N=60.

Table 14

Summary of Simple Slopes Analysis for NoGo Distractor N2 amplitude

Impulsivity	Trait Anxiety	Prediction ability of Sensory Sensitivity on N2 amplitude
High	High	significant (b=-.16, p=.04*)
High	Average	ns (b=-.00, p=.98)
High	Low	ns (b=.16, p=.04)
Average	High	ns (b=.02, p=.85)
Average	Average	ns (b=.05, p=.47)
Average	Low	ns (b=.08, p=.45)
Low	High	ns (b=.20, p=.15)
Low	Average	ns (b=.10, p=.23)
Low	Low	ns (b=.00, p= .99)

*p<.05, **p<.01. N=60.

Appendix B

Mean Image Ratings

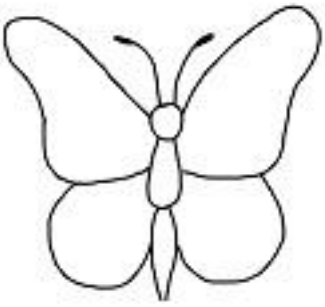
(N=60) for all images

*Except T44 (N=27)

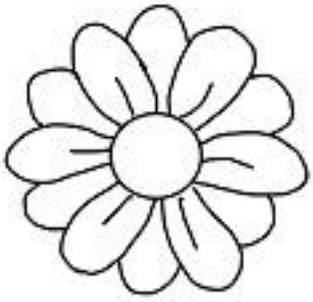
NT1- Apple
M= 4.72
SD=1.37

NT3- Mug
M= 4.68
SD= 1.26

NT5- Ice cream
M= 5.73
SD= 1.18

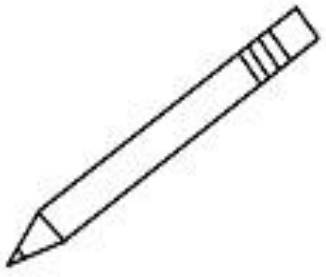


NT2- Butterfly
M= 5.37
SD= 1.13



NT4- Flower
M= 5.42
SD= 1.29

NT6- Lightbulb
M= 4.38
SD= 1.09



NT7- Pencil
M= 4.27
SD= 1.15

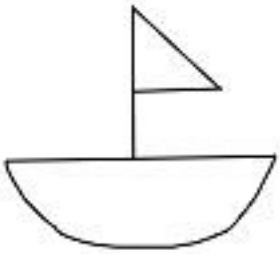
NT10- Snowman
M= 5.12
SD= 1.25

NT13- Shirt
M= 4.33
SD= .933

NT8- Pineapple
M= 5.50
SD= 1.17

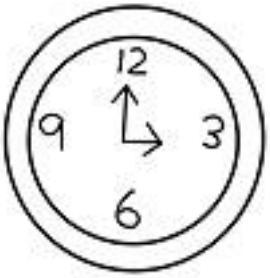
NT11- Sock
M= 4.17
SD= .827

NT14- Umbrella
M= 4.20
SD= 1.16



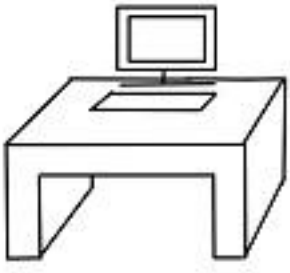
NT9- Boat
M= 4.45
SD= 1.36

NT12- Tree
M= 4.77
SD= 1.13



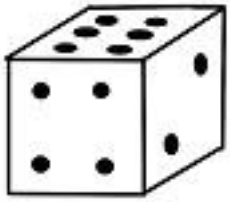
NT15- Clock
M= 4.25
SD=1.08

NT16- Baseball
M= 5.02
SD= 1.19



NT19= Desk
M=4.35
SD= .92

NT22- Magnet
M= 4.08
SD= .889



NT17- Dice
M= 4.27
SD= .95

NT20- Toothbrush
M= 4.33
SD= 1.10

NT23- Paintbrush
M= 4.42
SD=1.09

NT18- Cellphone
M= 4.97
SD= 1.44

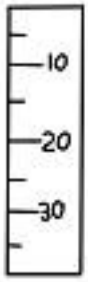
NT21- laptop
M=4.70
SD= 1.12

NT24- Pear
M= 4.55
SD= 1.02

NT25- Penguin
M= 5.40
SD= 1.20

NT28- Spoon
M= 4.28
SD= 1.01

NT31- Balloon
M= 4.78
SD= 1.20



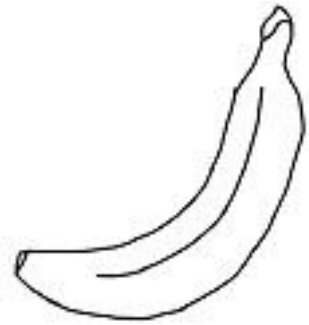
NT26- Ruler
M= 4.23
SD= .77

NT29- Wrench
M= 4.10
SD= .73

NT32- Cupcake
M= 5.85
SD= 1.20

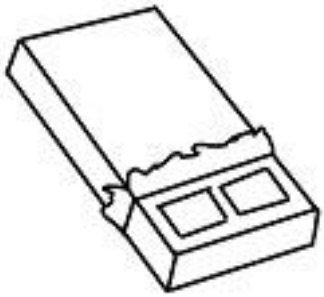
NT27- Shell
M= 4.02
SD= 1.10

NT30- House
M= 4.80
SD= 1.27



NT33- Banana
M= 4.80
SD= 1.27

NT34- Basketball
M= 4.83
SD= 1.44

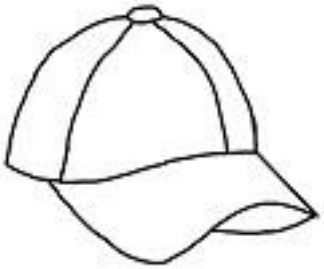


NT37- Chocolate
M=5.80
SD= 1.09

NT40- Lamp
M= 4.17
SD= 1.04

NT35- Book
M=4.52
SD=1.24

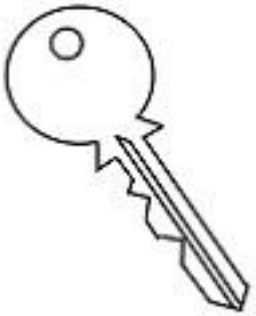
NT38- Coat
M= 4.23
SD= 1.27



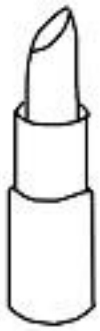
NT41- Hat
M= 4.60
SD= 1.15

NT36- Bread
M= 4.52
SD= 1.24

NT39- Couch
M= 4.50
SD= .930

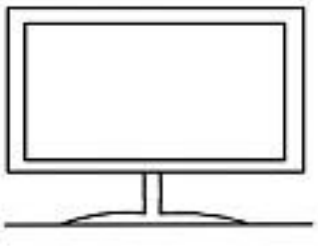


NT42- Key
M= 4.35
SD= .78



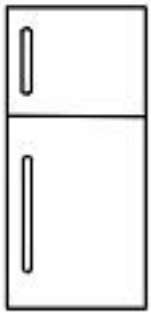
NT43- Lipstick
M= 4.58
SD= 1.14

NT46- Pizza
M= 65.90
SD= 1.45

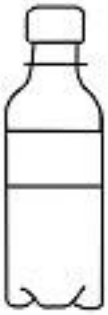


NT49- Television
M= 4.43
SD= 1.08

NT44- Medal
M= 5.52
SD= 1.03



NT47- Fridge
M=4.60
SD= 1.06



NT50- Water Bottle
M= 4.32
SD= 1.11

NT45- Maple Leaf
M= 5.48
SD= 1.68

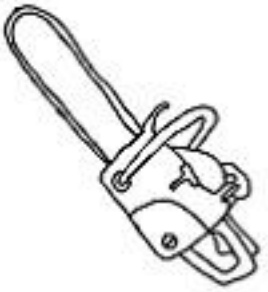
NT48- Ring
M=5.05
SD= 1.38

T1- Bear
M= 2.53
SD= 1.36

T2- Bomb
M= 2.57
SD= 1.47

T5- Fangs
M= 2.63
SD= 1.44

T8- Lion
M= 2.62
SD= 1.28



T3- Chainsaw
M= 2.87
SD= 1.16

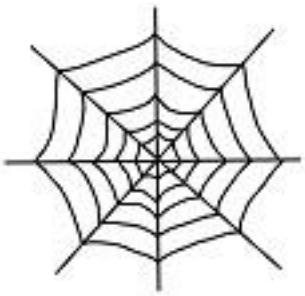
T6- Ghost
M=2.77
SD= 1.54

T9- Shark
M= 3.18
SD= 1.62

T4- Crocodile
M= 3.03
SD= 1.57

T7- Bloody Knife
M= 1.97
SD- 1.33

T10- Snake
M= 2.51
SD= 1.53



T11- Spider Web
M=3.02
SD= 1.23

T14- Gravestone
M= 2.08
SD= 1.18

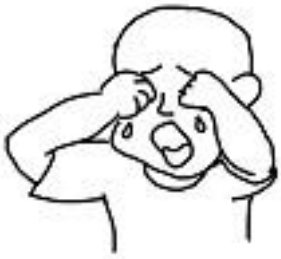
T17- Dog Barking
M= 2.95
SD= 1.53

T12- Syringe
M= 3.07
SD= 1.49

T15- Witch
M= 2.47
SD= 1.23

T18- Bat
M= 3.32
SD= 1.49

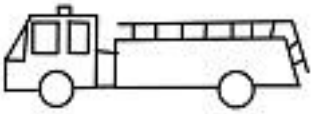
T13- Tarantula
M= 2.42
SD= 1.33



T16- Baby Crying
M= 2.50
SD= 1.23

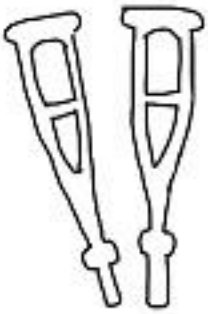
T19- Car Crash
M= 2.12
SD= 1.26

T20- Beetle
M= 2.40
SD= 1.46

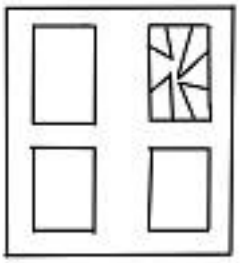


T23- Firetruck
M= 4.32
SD- 1.30

T26- Grim Reaper
M= 2.23
SD= 1.42

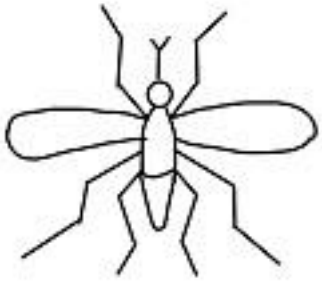


T21- Crutches
M= 2.93
SD= 1.40



T24- Broken Window
M= 2.90
SD= 1.11

T27- Police Badge
M= 4.23
SD= 1.14

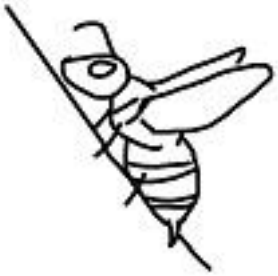


T22- Mosquito
M= 2.95
SD= 1.29

T25- Fire
M= 2.92
SD= 1.45

T28- Saw
M= 3.02
SD= 1.29

T29- Skull
M= 2.48
SD= 1.33

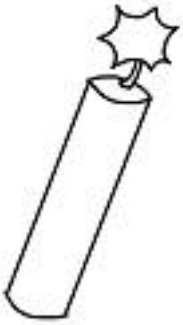


T32- Bee
M= 2.95
SD= 1.52

T35- Dragon
M= 2.68
SD= 1.62

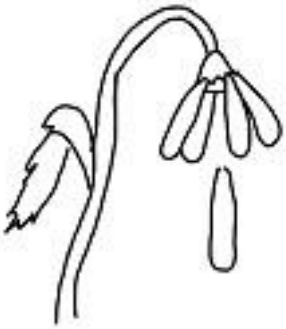
T30- Surgery
M= 3.68
SD= 1.36

T33- Caterpillar
M= 3.62
SD= 1.25

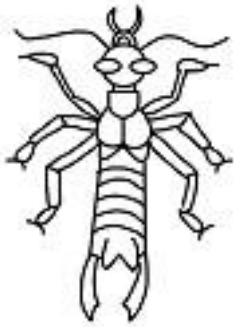


T36- Dynamite
M= 2.93
SD= 1.39

T31- Bloody Axe
M= 1.83
SD= 1.03



T34- Dead Flower
M= 2.87
SD= 1.28



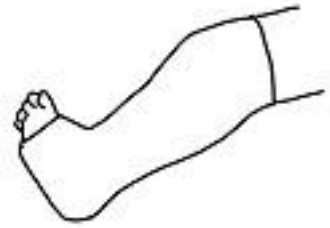
T37- Bug
M= 2.32
SD= 1.38

T38- Foot
M= 2.75
SD= 1.23

T41- Jack-O-Lattern
M= 3.82
SD= 1.37

T44- Piranha
M= 2.67
SD= 1.71

T39- Handcuffs
M= 2.60
SD= 1.20



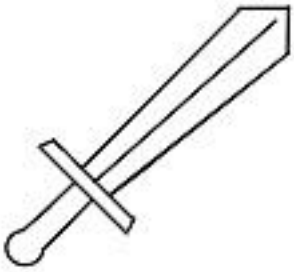
T42- Cast
M= 2.63
SD= 1.28

T45- Rat
M= 1.78
SD= 1.25

T40- House Fire
M= 1.95
SD= 1. 27

T43- Gun
M= 2.03
SD= 1.33

T46- Clown
M= 1.98
SD= 1.27



T47- Sword
M= 3.75
SD= 1.14

T50- Wolf
M= 2.25
SD= 1.40

T48- Thunderstorm
M= 3.43
SD= 1.32

T49- Tornado
M= 2.82
SD= 1.42

Appendix C

Brock University
Research Ethics Office
Tel: 905-688-5550 ext. 3035
Email: reb@brocku.ca

Bioscience Research Ethics Board

Certificate of Ethics Clearance for Human Participant Research

DATE:	12/19/2017		
PRINCIPAL INVESTIGATOR:	TEKOK-KILIC, Ayda - Child and Youth Studies		
CO-INVESTIGATOR(S):	Sid Segalowitz (sid.segalowitz@brocku.ca)		
FILE:	17-105 - TEKOK-KILIC		
TYPE:	Faculty Research	STUDENT:	Carolynn & Abe Hare & Omorogieva
		SUPERVISOR:	Ayda Tekok-Kilic

TITLE: TO GO OR NOT TO GO: Event-related potentials and pupil responses during a decision making task

ETHICS CLEARANCE GRANTED

Type of Clearance: NEW Expiry Date: 12/1/2018

The Brock University Bioscience Research Ethics Board has reviewed the above named research proposal and considers the procedures, as described by the applicant, to conform to the University's ethical standards and the Tri-Council Policy Statement. Clearance granted from **12/19/2017** to **12/1/2018**.

The Tri-Council Policy Statement requires that ongoing research be monitored by, at a minimum, an annual report. Should your project extend beyond the expiry date, you are required to submit a Renewal form before 12/1/2018. Continued clearance is contingent on timely submission of reports.

To comply with the Tri-Council Policy Statement, you must also submit a final report upon completion of your project. All report forms can be found on the Research Ethics web page at http://www.brocku.ca/research/policies-and-forms/research-forms.

In addition, throughout your research, you must report promptly to the REB:

a) Changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) All adverse and/or unanticipated experiences or events that may have real or potential unfavourable implications for participants;
c) New information that may adversely affect the safety of the participants or the conduct of the study;
d) Any changes in your source of funding or new funding to a previously unfunded project.

We wish you success with your research.

Approved: Sandra Peters

Sandra Peters, Chair
Bioscience Research Ethics Board

Note: Brock University is accountable for the research carried out in its own jurisdiction or under its auspices and may refuse certain research even though the REB has found it ethically acceptable.

If research participants are in the care of a health facility, at a school, or other institution or community organization, it is the responsibility of the Principal Investigator to ensure that the ethical guidelines and clearance of those facilities or institutions are obtained and filed with the REB prior to the initiation of research at that site.