Neural correlates of trait anxiety in sensory processing and distractor filtering

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Anxiety, generally defined as an anticipatory heightened state of arousal, has been shown to affect neural markers of cognition and executive components used in sensorimotor function; however, this has infrequently been shown in behavioural performance measures. The effects observed are presumably due to altered underlying prefrontal cortical activity that are then resolved by compensatory neural mechanisms. Despite these findings, the influence of trait anxiety on neural correlates of early stages of cognition and sensory processing, particularly in a multimodal context, has largely been unexplored. The current thesis aimed to address this gap by assessing whether trait anxiety impacts visual and tactile event-related potentials (ERPs) and performance accuracy in a bimodal sensorimotor task. Participants were instructed to attend toward one sensory modality and away from the other while producing a graded grip response. ERP amplitudes and latencies were analyzed to determine whether trait anxiety shows a relationship with neuroelectric markers of sensory and early cognitive processes. Behavioural distractor cost was represented by performance accuracy in the presence of a crossmodal distractor compared to without it. The tactile N70 ERP has been shown to be a marker of attentional relevance in the same visual-tactile experimental task used in the current thesis. Past studies using this experimental paradigm showed that conditions resulting in alterations in prefrontal cortical activity (i.e., continuous theta burst stimulation to the prefrontal cortex and a history of concussion) impacted modulation of this marker. Based on their findings, we hypothesized that trait anxiety would modulate tactile and visual ERPs as markers of sensory processing and attention, in particular, the N70 ERP. No relationship between trait anxiety and behavioural distractor cost was expected. Results indicated that trait anxiety impacted properties of ERPs shown to be susceptible to modulation by endogenous processes (i.e., attention): the tactile N70 as well as the visual P2 and P3. As hypothesized, trait anxiety showed no relationship to distractor cost. This study's findings support the notion that trait anxiety

impacts markers of neural processing, despite behavioural performance being maintained. It is possible that these neuroelectric differences are caused by alterations in neurotransmitter systems, such as the locus coeruleus-norepinephrine system, which are then reduced by compensatory mechanisms before the resulting movement is executed. Now that this relationship has been established in a multimodal context, future work should continue to explore the impact of trait anxiety on sensorimotor function from more mechanistic or ecologically valid perspectives.

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Chapter 1: Background

1.1 Introduction

At a given moment in time, the central nervous system (CNS) processes an abundance of incoming (afferent) sensory information from the environment (Cromwell, Mears, Wan, & Boutros, 2008). To prevent higher cortical areas of the brain from information overload, a mechanism known as sensory gating inhibits irrelevant information from the CNS (Cromwell et al., 2008). Attention modulates sensory gating (Adams, Popovich, & Staines, 2017) and allows for the inhibition of irrelevant information from our environment to influence the performance of goal-based actions (Cromwell et al., 2008).

Anxiety—a condition characterized by anticipatory negative thoughts, tension, apprehension, and worry, has not extensively been studied in sensory gating literature, but it has been shown to affect cognition and the goal-directed control of attention (Crocq, 2015). Anxiety is thought of as a spectrum, where inherent differences in levels of anxious disposition (otherwise known as trait anxiety) exist across healthy populations, and clinical cases represent an extreme within this range (Lang & McTeague, 2009). A dominating theory in anxiety literature called Attentional Control Theory (ACT) postulates that high trait anxiety impairs attentional control, impacting cognitive processing efficiency, but not necessarily performance effectiveness (Eysenck, Derakshan, Santos, & Calvo, 2007).

"Processing efficiency," regarded as a measure of functional activation in the brain's response to cognitive demands, is commonly assessed by neurophysiological and neuroimaging measures such as event-related potentials (ERPs) (Eysenck et al., 2007). In contrast, "performance effectiveness" relates to behavioural performance and is typically evaluated by accuracy and response times (Eysenck et al., 2007). Many studies have observed a negative relationship between anxiety on processing efficiency in distractor inhibition both in the presence and absence of threat, otherwise known as state anxiety. There is also evidence of reduced sensory gating in clinically anxious populations (e.g., those with obsessive-

compulsive disorder, post-traumatic stress disorder, and panic disorder) (Rossi et al., 2005; Skinner et al., 1999; Thoma et al., 2020), however little is known about how individual differences in trait-levels of anxiety within a healthy young adult population might impact sensory processing.

The current study addressed gaps in previous literature by examining the effect of trait anxiety in healthy adults on sensory gating and goal-directed processing of visual and tactile stimuli. Electroencephalography (EEG) was used to acquire event-related potentials (ERPs) in response to a bimodal sensorimotor attentional selection task previously used by Adams and colleagues (Adams, Andrew, & Staines, 2019; Adams, Niechwiej-Swezdo, McIlroy, & Staines, 2020; Adams et al., 2017). Neurophysiological assessment of early stages of selective sensory processing of visual and tactile stimuli in the cerebral cortex aimed to determine whether high levels of trait anxiety affected one's ability to attend toward and away from stimuli presented either alone or crossmodally. These findings evaluate the applicability of ACT towards whether trait anxiety can predict sensory gating and sensorimotor function. A greater understanding of how trait anxiety could affect the ability to filter sensory information from the environment in daily life which could contribute to the development of highly personalized educational accommodations, the development of aptitude assessments for jobs involving exposure to high sensory stimulation, as well as the optimization of public spaces (e.g., work, healthcare, and retail environments) to minimize distractibility in highly anxious individuals.

1.2 Literature Review

Every day, individuals are required to divide their attention between different sensory modalities and select relevant information to drive their behaviour (Grunwald et al., 2003). Attention is affected by many factors, including anxiety (Basten, Stelzel, & Fiebach, 2011; Bishop, 2009; Stout, Shackman, & Larson, 2013). Anxiety is often thought of as a multidimensional phenomenon that can be differentiated into two types: trait and state anxiety (Spielberger, 1966, as cited in Endler & Kocovski, 2001). Trait

anxiety refers to a proneness in personality towards hypervigilance and anticipatory negative thoughts, including a heightened reactivity toward threat and cognitive tendency to worry (Endler & Kocovski, 2001). In contrast, state anxiety is an acute condition in response to a situational stressor and is often thought of as an autonomic-emotional response (Endler & Kocovski, 2001). High trait anxiety is often referred to as a subclinical form of anxiety, which may predispose individuals to symptoms (e.g., cognitive biases) and negative affect that may lead to the development of anxiety and depressive disorders (Haller, Cramer, Lauche, Gass, & Dobos, 2014). Due to the interactive nature of the different dimensions of anxiety, individuals with varying levels of trait anxiety respond differently to state-anxiety-inducing situations (Endler & Kocovski, 2001). While both dimensions of anxiety are differentiated based on acuteness, they both contribute to the overall picture of an individual's reactivity towards threat (Endler & Kocovski, 2001).

Past research has shown that trait or dispositional differences in anxiety can affect executive functions implicated in sensory gating and sensorimotor control (Ansari & Derakshan, 2011b; Basten, Stelzel, & Fiebach, 2011; Hainaut & Bolmont, 2013). This literature review provides a brief overview of the relevance of research in trait anxiety, followed by insights gained from past research focused on cognitive implications, structural and functional alterations, as well as impacts on sensory gating and related functions found to date.

1.3 The Relevance of Anxiety as a Maladaptive Trait in Research

Anxiety is a prevalent and debilitating mental health condition that reduces quality of life and imposes a large economic burden on healthcare systems (Haller et al., 2014; Koerner et al., 2004). While symptoms of hypervigilance, nervousness, rapid heart rate or ventilation, sweating, panic attacks, and perceptual dysfunction (Gelenberg, 2000) are characteristic of disorders on the anxiety spectrum such as Generalized Anxiety Disorder (GAD), obsessive-compulsive disorder (OCD), and panic disorder (PD),

many individuals experience anxiety and its symptoms subclinically (Forster, Elizalde, Castle, & Bishop, 2015). Roughly 1 in 3 Canadians aged 18-39 reportedly experience moderate to severe anxiety (Centre for Addiction and Mental Health, 2022). Subclinical or subthreshold anxiety (i.e., that does not reach diagnostic criteria as per the current threshold of DSM-II-R, DSM-IV, or ICD-10) is even more common than anxiety disorders in the general population (Haller et al., 2014). In a systematic review based on European and North American data in the years leading up to 2013, subthreshold GAD was twice as prevalent as GAD in the general population (Haller et al., 2014). Hence, a large portion of the population experiences high levels of anxiety and accompanying symptoms, whether they meet diagnostic criteria or not. For this reason, it is vital to direct further research toward high trait anxious populations.

There is a well-established body of literature that suggests that anxiety is associated with altered processing of emotional stimuli and causes an attentional bias towards threat (see reviews by Bishop, 2007; Sussman, Jin, & Mohanty, 2016). However, there exists significantly less research that has examined how anxiety might affect cognition in the presence of affectively neutral stimuli. Some evidence suggests that goal-directed control of attention is impaired in high trait anxious (HTA) individuals both in the presence of threat (Pacheco-Unguetti, Acosta, Callejas, & Lupiáñez, 2010; Stout et al., 2013) and in the absence of it (Ansari & Derakshan, 2011a; Basten et al., 2011; Basten, Stelzel, & Fiebach, 2012; Bishop, 2009; Forster et al., 2015). Even in the absence of threat, anxiety has been linked to deficits in cognitive functions such as inhibition of irrelevant distractors (Bishop, 2009; Qi, Ding, & Li, 2013; Stout et al., 2013), working memory (Basten et al., 2011, 2012), response inhibition (Sehlmeyer et al., 2010; Xia, Mo, Wang, Zhang, & Zhang, 2020) and task switching (Wu, Ma, He, Xiang, & Qi, 2021). Given that sensory processing and sensorimotor integration employ executive functions such as these, they may also be affected by trait anxiety. This highlights an important gap in the literature, as few studies have addressed the relationship between anxiety as a maladaptive trait and how it might affect sensorimotor processes that drive behaviour.

1.4 Neurocognitive Foundations of Trait Anxiety

Attentional Control Theory (ACT)

Attentional Control Theory (ACT), developed by Eysenck et al. (2007), is a theory that defines anxiety's effect on cognition in non-clinical populations based on prior empirical work. One of its principles describes that anxiety impacts goal-directed attentional control, where high trait anxious (HTA) individuals' attention is more influenced by stimulus-driven neural processes compared to low trait anxious (LTA) individuals (Eysenck et al., 2007; Eysenck & Derakshan, 2011). These deficits are thought to be the consequence of an impaired central executive system (Eysenck et al., 2007) that acts on three lower-level functions: inhibition, switching, and updating (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000) based on Baddeley's multi-component model of working memory (Baddeley, 1986 as cited in Miyake et al., 2000).

Another notable assumption drawn from ACT is that anxiety is associated with reduced processing efficiency but not performance effectiveness (Eysenck et al., 2007). High trait anxious individuals tend to perform at a comparable level to those who are less anxious, presumably because of compensatory increases in neural effort. While these increases in neural effort signify a reduction of neural efficiency at performing the same task, their overall performance ability is not hindered; particularly, in cognitive tasks that require inhibition, switching, or updating (see reviews by Berggren & Derakshan, 2012; Eysenck et al., 2007; Eysenck & Derakshan, 2011). Research has also shown that when the cognitive demands are sufficiently high, there is a dissociation between performance in HTA and LTA groups, where high trait anxiety leads to compromised performance (Basten et al., 2011; Bishop, 2009). In sum, high trait anxious individuals are thought to require more neural effort to function comparably to those who are less anxious, which can compromise performance if adequately challenged.

Well-validated cognitive paradigms such as the Stroop task have been widely used to assess executive functions, but neurophysiological techniques are preferable to less direct behavioural techniques such as response time to assess neural processing efficiency during these paradigms. Response time and accuracy were concluded to be related to the outcome of processing rather than directly measuring its efficiency (Eysenck & Derakshan, 2011). For example, a recent study by Kamboureli and Economou (2021) found no differences in performance in the Stroop task between HTA and LTA individuals. Their finding supports ACT's account that performance effectiveness is broadly comparable between these groups, but the lack of measuring processing efficiency through more direct methods fails to account for the underlying effect that high trait anxiety may have on cognitive performance. This is a considerable limitation of studies solely using behavioural methods to assess processing efficiency.

Numerous studies from the past decade utilise neuroimaging techniques such as EEG (Qi et al., 2013) and functional magnetic resonance imaging (fMRI) (Basten et al., 2011, 2012; Bishop, 2009), as well as eye-tracking (Ansari & Derakshan, 2011a), as neurophysiological measures to address this limitation. Thus, to effectively assess the effect of trait anxiety on attentional processes, the combination of behavioural and neurophysiological methods to measure processing efficiency should be used.

Anxiety, Attentional Control Deficits, & the Prefrontal Cortex (PFC)

Dichotomous attentional models are commonly used to refer to selective attention. In goal-driven attentional processes, top-down control of attention regulates focus toward the subject's behavioural goals (Corbetta, Patel, & Shulman, 2008). In contrast, bottom-up attention refers to stimulus-driven processes (Corbetta et al., 2008). The attentional control deficits caused by trait anxiety are broadly characterized by diminished top-down control of attention, with greater emphasis on stimulus-driven, bottom-up processing (Eysenck et al., 2007; Eysenck & Derakshan, 2011). These deficits include a reduced ability to inhibit incongruent information in the colour word Stroop task (Basten et al., 2011) and impaired

inhibitory control in anti-saccades (Ansari & Derakshan, 2011b). Thus, these attentional biases seen in high trait anxiety further translate into cognitive biases affecting individual executive functions.

The prefrontal cortex is responsible for many critical cognitive and executive functions affected by anxiety; particularly relevant for this work are the goal-directed control of attention and sensory gating (Knight, Staines, Swick, & Chao, 1999). Past research in clinically anxious populations demonstrated a dysregulation of the recruitment of frontal cortical regions involved in attentional control, namely, the dorsolateral prefrontal cortex (DLPFC) and anterior cingulate cortex (ACC) (Bishop, 2009; Forster et al., 2015). Both of these regions are implicated in reactive control to incoming afferent information, otherwise known as inhibition (Forster et al., 2015).

There are contradictory findings as to whether anxiety is associated with an upregulation or downregulation of DLPFC activity in tasks requiring attentional control. For example, fMRI studies in subclinical and clinically anxious cohorts have demonstrated contradictory findings related to DLPFC activity in cognitive control without the presence of emotional stimuli. Contrary to Eysenck's (2007) arguments in Attentional Control Theory which suggest that neural areas responsible for the goal-directed control of attention are upregulated as a form of compensation due to reduced processing efficiency, Bishop (2009) found weaker activation in these areas. While many studies support ACT's principle that activity in neural areas responsible for the goal-directed control of attention such as the right DLPFC are upregulated (Basten et al., 2011, 2012; Forster et al., 2015; Morgenroth et al., 2019), there remains inconsistency as to whether anxiety results in hyper- or hypo-frontality (increased or decreased neural activity in the prefrontal cortex, respectively). Basten et al. (2011) used an fMRI-adapted Stroop task to assess whether trait anxiety affects inhibitory processing efficiency and performance effectiveness. HTA individuals required more neural effort as evaluated by BOLD activity in the DLPFC (Basten et al., 2011). Additionally, abnormal coupling between the DLPFC with other task-related areas (i.e. dACC, left fusiform gyrus, inferior frontal junction) reflected reduced cortico-cortical functional connectivity (Basten

et al., 2011). In a later study investigating the effects of trait anxiety on maintenance and manipulation of working memory, Basten and colleagues (2012) found stronger activation of the right DLPFC in HTA compared to LTA individuals. The authors argued that this reflected increased cognitive effort in the HTA participants to perform at a comparable level as the LTA participants (Basten et al., 2012). This work supports ACT's account that processing efficiency is reduced in HTA compared to LTA individuals due to the adoption of compensatory mechanisms, but does not affect performance effectiveness (Eysenck et al., 2007). The current consensus is that the dysregulation of prefrontal areas depends on the nature of the task and executive functions employed (Eysenck & Derakshan, 2011).

Structural & Functional Bases of Trait Anxiety

The neurobiological basis of trait anxiety's impact on executive function and cognition has yet to be fully understood. Recent research suggests that the dysregulation of attention in high relative to low trait anxiety may involve neurocognitive phenotypes based on differences in structural and functional architecture in the brain. From a structural perspective, MRI source-based morphometry analysis by Saviola and colleagues (2020) revealed that trait anxiety is functionally associated with increased structural grey matter in prefrontal cortical areas of the Default Mode Network (DMN). Other phenotypic characteristics of trait anxiety in the brain include abnormally increased cortical thickness in the amygdala and cingulate regions (Potvin et al., 2015), increased functional connectivity between the medial prefrontal cortex (mPFC) and amygdala during resting state (Kim, Gee, Loucks, Davis, & Whalen, 2011), and altered white matter connectivity (Yang, Zhang, Lu, Ren, & Li, 2020). The study of neural oscillatory activity also shows promise for furthering the understanding of network alterations in those with anxiety (Aftanas, Pavlov, Reva, & Varlamov, 2003). Further research is needed to determine whether these structural and functional alterations in trait anxiety directly cause the deficits observed in neural efficiency, or whether they compensate for other downregulated areas within a network.

1.5 Neurotransmitter Influences on Arousal, Sensory Processing, and Attention

What has long been known is that molecules such as monoamines and acetylcholine are critical in modulating sensory processing and cognition (Liu, Zhao, & Guo, 2018); however, less is known about how the complex interplay of neurotransmitters and hormones related to anxiety may impact sensory and cognitive functioning on a trait level. There is substantial evidence to suggest that multiple types of neurotransmitters are imbalanced in anxiety disorders, including norepinephrine (NE), dopamine (DA), serotonin (5HT), and acetylcholine (ACh) (Liu et al., 2018). NE and DA are catecholamines; secreted by the adrenal glands, they act as both hormones and neurotransmitters in the regulation of the sympathetic nervous system and arousal (Paravati et al., 2021). Berry et al. (2019) suggest that in healthy adults, reduced DA neurotransmission may contribute to high trait anxiety. 5HT, thought to play a role in Generalized Anxiety Disorder (GAD), also plays an important role in the suppression of irrelevant sensory inputs that may disrupt motor performance (Lucki, 1998). ACh is another molecule that is found to have implications in attentional processing as well as in anxiety (Higley & Picciotto, 2014). With discussion of all neurotransmitter systems being outside the scope of this thesis, possible NE influences will be discussed further.

The Locus-Coeruleus-Norephinephrine System

The LC-NE (locus coeruleus-norephinephrine) theory is one possible explanation of the mechanism in which NE impacts prefrontal cortical activity via the locus coeruleus, a collection of NE neuronal cell bodies (Aston-Jones & Cohen, 2005b). Discharge activity from the locus coeruleus regulates the release of norepinephrine (NE) to the cerebral cortex (Lecas, 2004). Though traditionally thought to be linked to arousal, NE is implicated in many systems including sensory processing and cognition (Jacob & Nienborg, 2018). Multiple theories have attempted to explain this relationship, with the consensus that the LC-NE system contributes to the augmentation of neuronal responses to goal-

relevant stimuli and the suppression of neuronal signals in response to less-relevant information (Aston-Jones & Cohen, 2005a, 2005b; Mather, Clewett, Sakaki, & Harley, 2016). Aston-Jones & Cohen (2005a) proposed the adaptive gain theory, wherein increased LC-NE activity increases the neural "gain" and "signal-to-noise." Network reset theory is based upon neuromodulation in invertebrates but described analogously in mammals, where the NE system's task-related LC activity has the ability to reset and quickly adapt to changing environmental demands (Bouret & Sara, 2005). Mather and colleagues (2016) built on these two prior models by proposing the Glutamate Amplifies Noradrenergic Effects (GANE) theory. They suggest that upon exposure to a novel stimulus, the LC fires in phasic bursts, causing cortical desynchronization (Mather et al., 2016). The GANE theory further suggests that NE, together with glutamate, amplifies interneuronal NE and glutamate, creating "hotspots" of amplified neuronal activity (Mather et al., 2016). Though the "hotspot" model can be explained conceptually, there is little evidence supporting a physiological basis for this. The consensus between these theories is that the LC is thought to influence activity of the PFC, which can further impact task execution (see review by Aston-Jones & Cohen, 2005b). Furthermore, the LC-NE system has a substantial impact on glutamatergic systems (Nieuwenhuis, Aston-Jones, & Cohen, 2005), which may impact neuronal excitation based on task demands.

1.6 Anxiety & Sensory Processing: Sensory Gating & Distractor Inhibition

The association between trait anxiety and how it may impact sensory gating ability remains unclear, but prior research in healthy, high trait anxious populations suggests that there may be a negative relationship (Chan, von Leupoldt, Bradley, Lang, & Davenport, 2012; Duley, Hillman, Coombes, & Janelle, 2007). The first evidence of a relationship between individual differences in anxiety and sensorimotor gating in a healthy population was shown by Duley et al. (2007), where prepulse inhibition (PPI) was shown to be impaired in HTA compared to LTA individuals at rest (Duley et al., 2007). PPI,

also known as startle reduction, refers to the attenuation of the startle reflex magnitude of a startling stimulus following exposure to a stimulus of low intensity, otherwise known as a prepulse (Duley et al., 2007). Interestingly, trait anxiety had no effect on PPI after an acute bout of exercise (Duley et al., 2007). Chan et al., (2012), found that deficits in respiratory sensory gating (respiratory-related evoked potential N1 peak gating ratios from second relative to first inspiratory occlusions) could also be predicted by self-reported measures of anxiety. Further research needs to be conducted to determine how high trait anxiety may affect sensory gating across all sensory modalities.

Sensory gating studies in clinically anxious populations have been conducted more extensively. A variety of anxiety disorders result in deficits in sensory gating measures including auditory M50/P50 peak irregularities in post-traumatic stress disorder (PTSD) (Holstein, Vollenweider, Jäncke, Schopper, & Csomor, 2010; Hunter et al., 2011), as well as prepulse inhibition (PPI) deficits in patients with panic disorder (PD) (Ludewig, Ludewig, Geyer, Hell, & Vollenwider, 2002) and PTSD (Holstein et al., 2010). Future research should continue using similar measures within subclinically anxious populations to assess potential sensory gating differences related to anxiety severity.

Grunwald and colleagues (2003) suggested that sensory gating is a multi-step process, with earlier stages occurring in the temporo-parietal and prefrontal neocortex (Yamaguchi & Knight, 1990) and later stages occurring in the hippocampus. Relevant stimuli are presumably processed to a greater extent, whereas irrelevant sensory stimuli are "gated" out of one's attention earlier in the processing stream to prevent overloading higher cortical areas with information (Grunwald et al., 2003). At early stages of sensory processing, one of the many functional roles of the prefrontal cortex is the gating of afferent sensory information (Yamaguchi & Knight, 1990). The DLPFC is believed to play a crucial role in sensory gating, the goal-directed control of attention, and actively inhibiting irrelevant information (Chao & Knight, 1995).

Because DLPFC activity is altered during cognitive tasks in healthy HTA compared to LTA individuals (Basten et al., 2011, 2012; Bishop, 2009), sensory gating in HTA individuals may also be compromised. Although anxiety is associated with a reduced ability to inhibit irrelevant distractors in both the presence and absence of threat (Ansari & Derakshan, 2011b; Basten et al., 2011, 2012; Bishop, 2009; Stout et al., 2013), prior studies have failed to address whether this occurs with exposure to multiple sensory modalities. Future research is needed to address the influence of trait anxiety on distractor inhibition in multimodal contexts to increase ecological validity and generalizability to everyday cognition.

1.7 Rationale, Objectives, and Hypotheses

Subclinical anxiety is a health and economic burden, with many individuals experiencing symptoms of anxiety disorders without intervention (Haller et al., 2014; Mental Health Research Canada, 2021). Aside from the many symptoms observed in anxiety including those associated with emotional distress (e.g., sweating, dizziness, rapid heart rate), the neurobiological basis of the perceptual, cognitive, and attentional symptoms are less understood (Gelenberg, 2000). While there is a well-established bias of attention towards threat in those with high dispositional levels of anxiety (for review, see Sussman et al., 2016), more recent research has turned to examine the effect of dispositional anxiety on the ability to suppress distractors from one's immediate environment in the absence of threat (Ansari & Derakshan, 2011a; Basten et al., 2011, 2012; Bishop, 2009). A region shown to be functionally dysregulated during cognitive tasks in individuals with high trait anxiety is the DLPFC (Basten et al., 2011, 2012; Bishop, 2009; Morgenroth et al., 2019). This region is also necessary for sensory gating (Chao & Knight, 1995). Past findings of irregularities in these areas in cognitive tasks requiring the inhibition of irrelevant stimuli, particularly in the DLPFC (Basten et al., 2011, 2012; Bishop, 2009; Morgenroth et al., 2019), may translate to modality-specific gaiting deficits. Prior studies have largely focused on the effect of trait

anxiety on specific cognitive control functions (e.g., inhibition, shifting, and working memory) using visual stimuli (Ansari & Derakshan, 2011a; Ansari & Derakshan, 2011b; Basten et al., 2011, 2012; Bishop, 2009; Stout et al., 2013). No studies to date have observed the effects of trait anxiety on sensory gating and sensorimotor function when exposed to sensory stimuli of two different modalities. The use of bimodal stimuli (visual and tactile) increases the ecological validity of the study's findings compared to those solely focused on visual perception, because the way that we normally perceive the world involves sensory gating of streams of multiple modalities.

This experimental EEG study used a pseudorandomized block design to evaluate whether individual differences in trait anxiety affect visual and tactile sensory processing and performance in a bimodal sensorimotor task in healthy young adults. Trait anxiety was evaluated by a self-report questionnaire called the State-Trait Anxiety Inventory (STAI) trait scale (STAI-Y2) (Spielberger, 1983). Trials consisted of the presentation of visual and vibrotactile stimuli either alone or simultaneously. Participants directed their attention to either visual or tactile stimuli and ignore the other sensory modality within a given experimental block. Finally, they responded to the attended stimulus by squeezing a pressure-sensitive response bulb proportionately to the amplitude of the stimulus strength, which was established in a training session. Sensorimotor performance was assessed with the cost of the distractor relative to the optimal grip strength, otherwise known as distractor cost. In addition to this behavioural measure of performance, this study employed quantitative analysis of sensory ERP amplitudes as neural correlates of sensory gating on the processing of visual and tactile modalities in a sensorimotor task. ERP analysis of early tactile and visual potentials offer high temporal resolution to assess the neural mechanisms behind the relevancy-based sensory gating process.

In a series of experiments utilising the same crossmodal visual-tactile sensorimotor attentional selection task as in the current experiment, prior studies by Adams and colleagues (2017, 2019, 2020) determined that the N70 tactile ERP (which is generated in SI and occurs early in the tactile sensory

processing stream; Yamaguchi & Knight, 1990) is enhanced when a stimulus is task-relevant and attenuated when a stimulus is task-irrelevant. Prefrontal and temporo-parietal areas are generally responsible for the orienting of attention to achieve goal-driven behaviours, with early stages of sensory gating occurring in these areas of the cerebral cortex (Grunwald et al., 2003; Yamaguchi & Knight, 1990). Past research using the same experimental paradigm as the current study found that inhibition of the prefrontal cortex with continuous theta-burst stimulation (cTBS) caused a reduction in the ability to facilitate N70 amplitude when attending toward a tactile stimulus (Adams et al., 2019), failing to enhance its amplitude relative to when attending away. Furthermore, frontal lesion patients have shown greater amplitude and latency of somatosensory-evoked potentials (SEPs) including N67 (N70) with median nerve stimulation compared to controls (Yamaguchi & Knight, 1990). Yamaguchi & Knight (1990) speculated that this enhanced effect may have been due to a loss of inhibitory connections between the prefrontal and somatosensory cortices of these patients compared to controls. These findings conjunctively demonstrated the vital role of the PFC in the modulation of the somatosensory N70. Thus, in the current paradigm, quantitative analysis of the amplitude of the N70 tactile ERP was used as a neurophysiological marker of attentional task-relevance and sensory inhibition.

The purpose of this study was to observe the effect of individual differences in trait anxiety on sensory processing, gating, and sensorimotor function. The sensory selection task from Adams and colleagues (2017; 2019; 2020) involved the use of multiple cognitive functions: selective attention, sustained attention, sensory reweighting, switching, and inhibition. Analysis of ERP amplitudes and latencies helped extrapolate whether and at which points in the visual and somatosensory processing streams trait anxiety showed a relationship to electrical markers of sensory and cognitive processing. Distractor cost (relative performance accuracy in crossmodal conditions compared to unimodal) represented the outcome of processing, otherwise known as behaviour. This task also allowed for analysis early in the processing streams of multiple modalities (tactile and visual), as opposed to most studies in

this field which have focused solely on visual cues (i.e., Basten et al., 2011, 2012; Bishop, 2009; Forster et al., 2015).

1.8 Objectives & Hypotheses

ACT (Eysenck et al., 2007) and past findings from Adams et al. (2017, 2019, 2020) were used to inform the hypotheses for the proposed study. The objectives and corresponding hypotheses are as follows:

Objective 1: To assess the effect of trait anxiety (based on STAI-Y2 score) on sensory processing and gating of visual and tactile stimuli.

Hypothesis 1a. If high trait anxiety impaired the top-down control of attention, N70 ERP amplitude would be larger in HTA compared to LTA individuals in trials where participants were instructed to attend to visual stimuli in the presence of a tactile distractor. This assumption was based on Adams et al. (2017, 2019, 2020)'s findings that described the N70 ERP as a marker of relevancy-based gating, which was attenuated with downregulation of the PFC with cTBS and in individuals with a history of concussion. This hypothesis is linked to anxiety based on prior work demonstrating a reduction in the top-down control of attention related to anxiety (Ansari & Derakshan, 2011b) and greater emphasis on bottom-up processing. Maintenance of the somatosensory stimulus in one's selective attention when required to attend away (toward visual) would signify a reduced ability to divert attention to the relevant modality and inhibit irrelevant sensory information from being gated out of the processing stream (Grunwald et al., 2003). Failure to gate somatosensory information from one's attention would reflect dysregulation of engagement of higher cortical areas when attempting to allocate one's attention to the required modality (Grunwald et al., 2003).

Hypothesis 1b. Early somatosensory (P50, P100, N140) and visual ERPs (P1, N1, P2) would be modulated by trait anxiety based on task relevance and stimulus presentation. In addition to the

N70 somatosensory-evoked ERP, Adams et al. (2017) found that the P2 visual ERP was significantly attenuated when participants were instructed to attend away from visual stimuli (toward tactile) compared to when they were instructed to attend toward visual stimuli. This exploratory analysis addressed the possibility for other ERPs, particularly the P2, as being modulated by trait anxiety while factoring in attention relative to the sensory modality of focus within a given block (attend toward, attend away) and stimulus exposure (unimodal or bimodal).

Objective 2: To determine whether trait anxiety affects sensorimotor performance accuracy (as evaluated by distractor cost) when exposed to a stimulus presented concurrently with a distractor (VTd, TVd) compared to without (V, T, respectively).

Hypothesis 2. Distractor cost, a behavioural measure of performance accuracy or "effectiveness", would not be affected by trait anxiety. This prediction is based on prior studies indicating the same level of accuracy in more anxious compared to less anxious individuals in cognitive tasks that assess executive functions despite reduced neural activation and functional connectivity (Ansari & Derakshan, 2011a; Basten et al., 2012; Bishop, 2009). Although Basten et al. (2011) found a performance cost in HTA relative to LTA individuals in the Stroop Task, they attributed it to the high attentional demands of the task or the potentially fear-inducing fMRI scanner environment. This experiment helped distinguish the consequences of high trait anxiety on performance effectiveness in a novel context.

Chapter 2: Methods

2.1 Participants

Sample size was calculated with an *a priori* power calculation using G*Power 3.1 software (v3.1.9.6; Faul, Erdfelder, Lang, & Buchner, 2007; 2009). Using the "Linear multiple regression: Fixed model, R^2 deviation from zero" setting in the F test family, sample size was calculated with the following specifications: large effect size $f^2 = 0.35$, alpha error probability = 0.05, power = 0.8, and one predictor (trait anxiety). This calculation output an *a priori* sample size of 25 participants.

The recruitment goal of twenty-five participants was surpassed. Twenty-nine healthy young adults (17 females and 12 males ranging from 18-36 years, $M_{age} \pm SD_{age} = 23.14 \pm 3.92$ years, $M_{STAI\text{-}Y2} \pm SD_{STAI\text{-}Y2} = 41.59 \pm 10.44$; $Mdn_{STAI\text{-}Y2} = 39$) from the University of Waterloo were recruited to participate in this study. Exclusion criteria for potential subjects were as follows: neurological illness or impairment, diagnosis of psychiatric disorder other than Generalized Anxiety Disorder (GAD), a history of brain injury or concussion, prior history of substance abuse, left-handedness, and consumption of psychotropic drugs less than 2 weeks before attending the experimental session. One participant (male) was excluded due to later self-reported Attention-Deficit Hyperactivity Disorder (ADHD), and another male was excluded due to a misunderstanding of task instructions. One female was excluded due to a language barrier, causing improper execution of task instructions. A resultant number of twenty-six participants were included for analysis (16 females and 10 males ranging from 18-33 years; $M_{age} \pm SD_{age} = 22.69 \pm 3.18$ years; $M_{STAI\text{-}Y2} \pm SD_{STAI\text{-}Y2} = 41.35 \pm 10.60$; $Mdn_{STAI\text{-}Y2} = 39$). Informed written consent was obtained prior to beginning the study. This study was approved by the University of Waterloo Research Ethics Board.

2.2 Questionnaires

Prior to attending the experimental session, participants completed a pre-screening questionnaire with all exclusion criteria specified to determine eligibility (Qualtrics, Provo, UT). Upon attending the experimental session, participants were given verbal instructions and an information consent letter to review and sign. Once written consent was obtained, two self-report paper-and-pencil questionnaires were administered. Due to asymmetries between the left and right hemispheres in the brain (Weinberger, Luchins, Morihisa, & Wyatt, 1982), only right-handed individuals were recruited to reduce potential interhemispheric variability in ERP analysis. A shortened version of the Edinburgh Handedness Inventory (EHI) was used to confirm that each participant was right-handed (Oldfield, 1971; PsyToolkit, 2021; Veale, 2014). State and trait anxiety were evaluated with the State-Trait Anxiety Inventory for Adults™ (STAI) forms Y1 and Y2, respectively. The STAI is a 40-item measure of self-reported levels of anxiety based on a 4-point Likert scale (Spielberger, 1983). Although the STAI assesses both state and trait anxiety, it is commonly used as a measure of individual differences in anxiety in related literature examining the relationship between non-clinical anxiety and cognition (for example, Basten et al., 2011, 2012; Bishop, 2009). The STAI trait scale (form Y2) was used as the measure of trait anxiety.

2.3 Experimental Task

Setup

Upon questionnaire completion, participants were fitted and prepped for an elasticized EEG cap containing 32 surface electrodes (32 channel Quik-Cap, Neuroscan, Compumedics, NC, USA) that was worn for the duration of the experiment. Prior to putting on the cap, a gentle skin abrasive gel was applied to the mastoid processes behind the ears to remove oil and debris from the surface of the skin. Rubbing alcohol was used to eliminate residue. Reference electrodes were placed on the cleaned area on the left

and right mastoid processes prior to applying the EEG cap. After being measured for positioning on the head, conductive gel was injected into each of the electrodes to allow for electrical signals from the brain to conduct from the scalp to the electrode. Electrical impedance was maintained at less than 5 kiloOhms (kΩ).

Following EEG cap preparation, participants were seated comfortably in the experimental booth for the duration of the experiment (see Figure 1). Their gaze was fixed on a computer monitor that was positioned on a desk in front of them for visual stimulus delivery. The palmar surface of the second digit of their left hand rested on a vibrotactile device for tactile stimulus delivery. The experimental task required participants to respond with a pressure-sensitive bulb that was held in their right hand.

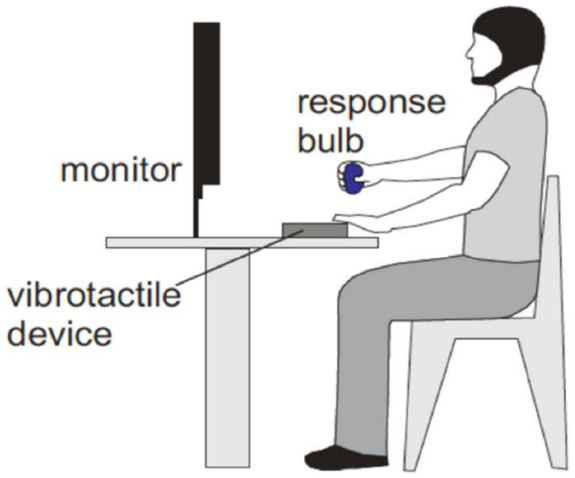

Figure 1. Experimental setup (Adams et al., 2017, 2019, 2020). Following EEG cap setup, participants were seated in front of a monitor that presented visual stimuli. The inner surface of the second digit of the left hand rested on a custom-made vibrotactile device that delivered tactile stimulation. The right hand held a pressure-sensitive bulb for generating behavioural responses.

Stimuli

Stimuli were presented as unimodal visual, unimodal vibrotactile, or simultaneously as bimodal visual and tactile (see Figure 2). Using a custom-made program in LabVIEW (version 2016; National

Instruments), analog vibratory signals were generated from digital waveforms (NI USB-6341 National Instruments, Austin, TX) and amplified (Bryston 2BLP, Peterborough, ON) to deliver tactile stimuli to the second digit of the left hand. A single trial consisted of 1 stimulus, with a total of 60 trials per experimental block. Each stimulus was presented for 500 milliseconds with 3 seconds in between trials for a total of 3.5 seconds per trial. Each block lasted 3.5 minutes. There were 12 blocks for a total of 720 trials, making the duration of the experimental task approximately 45 minutes. Participants were instructed to judge the strength or amplitude of the stimuli and produce a graded motor response by squeezing the response bulb to match the approximate strength of the stimuli (see Figure 2).

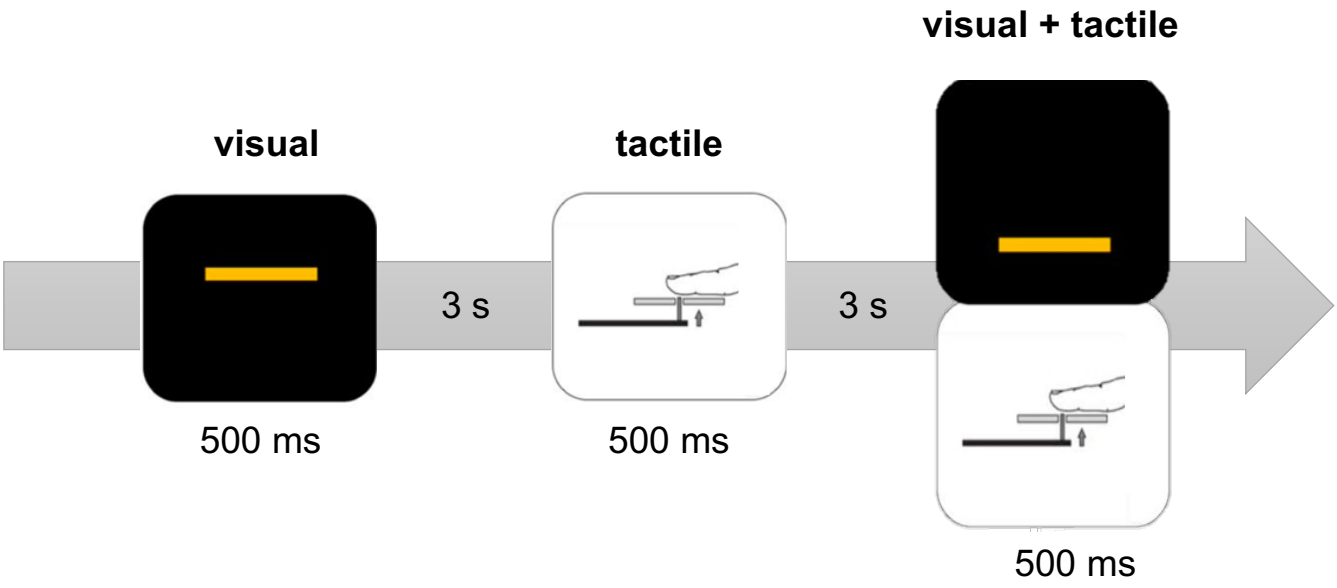

Figure 2. Sample experimental trials. Three stimulus types were pseurorandomized throughout the experimental task: visual alone, tactile alone, or visual and tactile stimuli presented simultaneously. Visual stimuli were presented as orange horizontal bars of varying elevations from the bottom of the monitor. Tactile stimuli were presented as vibrations of varying intensities to left index finger. Stimulus presentation occurred for 500 ms followed by 3 seconds for the participants to respond.

Training

Before commencing the experimental trials, participants partook in a training session lasting approximately 5 minutes in which they received feedback on their responses. This familiarized them with the relationship between the amplitudes of the stimuli and the required grip force to generate as accurate of a response as possible. An orange horizontal target bar was presented on the monitor. Subjects were instructed to squeeze the response bulb with enough force to elevate a second blue horizontal bar to match the height of the orange bar. The pressure applied to the rubber bulb caused a change in air pressure within a rubber tube, and a pressure sensor recorded this as a voltage proportional to the applied pressure. Vibrotactile stimuli and their amplitude were controlled by a custom LabVIEW (version 8.5, National Instruments, Austin, TX) program so that when participants responded to the visual demands of the task by applying force to the response bulb, a vibration of proportional strength was applied to the palmar surface of their left index finger. As the elevation of the orange bar increased, the required force of the right hand on the rubber bulb to elevate the blue bar increased with the corresponding strength of vibrotactile feedback to the left index finger. Subjects were instructed to pay attention to the relationship between the strength of the force applied to the bulb, the amplitude of the moving bar, and the strength of the vibration to their left index finger. This training session provided participants with visual feedback to teach them the relationship between the amplitudes of the stimuli and the corresponding force to apply to the response bulb.

Attentional Instructions

In each experimental block, stimuli appeared pseudo-randomly as a unimodal visual stimulus, unimodal tactile stimulus, or bimodal stimulus (visual and tactile onset simultaneously). There were two types of attentional blocks: attend visual or attend tactile. Participants were instructed to divert their

attention to a single modality, either visual or tactile, for the duration of a given block. Attentional instruction blocks were counterbalanced between participants (i.e., half started with tactile with the next block as visual, and vice versa) and interleaved, with an equal number of blocks designated to attend to each modality (6 out of 12). In visual attention blocks, participants attended to unimodal visual stimuli (V), ignored distractor unimodal tactile stimuli (Td), and attended toward the visual component of the bimodal stimulus while ignoring the tactile component (VTd). In tactile attention blocks, participants attended toward unimodal tactile stimuli (T), ignored distractor unimodal visual stimuli (Vd), and attended toward the tactile component of the bimodal stimulus while ignoring the visual component (TVd). Subjects were instructed to respond to the trials they were attending toward by generating the appropriate grip strength to the rubber bulb.

	Stimulus Type		
	Unimodal		Bimodal
Attentional Instructions	Visual alone	Tactile alone	Simultaneous
Attend **visual** (6 blocks)	V	Td	VTd
Attend **tactile** (6 blocks)	Vd	T	TVd

Figure 3: Stimulus presentation. In each block, participants were instructed to attend toward visual or tactile stimuli. Stimuli were presented as unimodal visual, unimodal tactile, or bimodally (visual and tactile simultaneously) in each block. In visual attention blocks, participants were instructed to attend toward the visual stimuli (V), with tactile stimuli as distractors (Td). In tactile attention blocks, participants were instructed to attend toward tactile stimuli (T), with visual stimuli as distractors (Vd). For bimodal stimuli, visual and tactile stimuli were presented simultaneously (VTd for visual attention blocks, TVd for tactile attention blocks).

2.4 Electroencephalography

Data Acquisition

Behavioural data was recorded using a custom program written in LabVIEW. This program sent event codes to a continuous EEG file indicating the precise stimulus timing and type. Continuous EEG files commenced at the start of each experimental block and ended once all trials of a given block were completed. Trial types (V, T, Vd, Td, VTd, TVd) were assigned event codes during the experimental task which allowed for ERP analyses time-locked to stimulus onset.

EEG data were recorded from 11 electrode sites (32-channel Quik-Cap, Neuroscan, Compumedics, NC, USA) in accordance with 10-20 international system for electrode placement and referenced to connected mastoid electrodes (FP2, FCz, Cz, CP4, C4, P4, CP3, Pz, Oz, O1, and O2). Due to restrictions placed as a result of the COVID-19 pandemic, the number of electrodes prepared and used in data collection were limited. Topographic plots were not developed for this reason. Electrode FP2, located near the right eye, was used to detect blinks. EEG signal was amplified and digitized at 500 Hz (SynAmps2, Scan 4.5, Compumedics Neuroscan, NC, USA) prior to being saved for offline analysis. Data was collected with a low-pass filter of 30 Hz to eliminate high frequency neuroelectric or muscular activity and from the continuous EEG signal.

ERP Analysis

EEG data analysis occurred offline in MATLAB (*MATLAB*, 2022) using EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014) plugins. Trials were appended based on attentional instructions, for a total of 2 continuous EEG files: one when attending toward tactile, and one for when attending toward visual (for a reminder of stimulus types within each respective block type, see Figure 3). A 0.1 Hz high-pass filter was applied during pre-processing in EEGLAB, for a total bandpass

of 0.1-30 Hz. Artifact detection and ERP operations were performed in ERPLAB. Epochs were 600 ms in length, beginning 100 ms prior to stimulus onset and extending to 500 ms following stimulus exposure. Automatic artifact detection was conducted in ERPLAB and consisted of two methods applied to each full epoch: (1) Simple voltage threshold of -75 to +75 microvolts and (2) Moving window peak-to-peak threshold of -65 to +65 microvolts (moving window full width of 200 milliseconds, window step of 100 milliseconds). Each epoch was manually observed and included in the average if deemed acceptable, excluding those with noticeable artifacts (e.g., eye blinks, facial muscle flexion). Epochs were baseline corrected to the prestimulus period (100 milliseconds before stimulus onset) in ERPLAB.

Peak amplitudes within predetermined post-stimulus latencies as well as peak latency were extracted from the electrode that showed the largest evoked potential amplitude in the group-averaged ERP traces. These values were extracted for early somatosensory and visual ERP components within the following predetermined latency windows: somatosensory – P50 (45-75 ms), N70 (60-80 ms), P100 (80-120 ms), N140 (125-175 ms); visual – P1 (125-175 ms), N1 (180-220 ms), P2 (225-285 ms), P3 (295-495 ms). The P50, N70, P100, and N140 somatosensory-evoked ERPs occur in the cerebral cortex following exposure to a tactile stimulus. The P50 and N70 ERPs occur earliest in the tactile sensory processing stream and are maximally generated in the primary somatosensory cortex (SI) contralateral to stimulation (Yamaguchi & Knight, 1990; Hämäläinen, Kekoni, Sams, Reinikainen, & Näätänen, 1990). Because all participants received tactile stimulation to the left index finger, tactile P50 and N70 ERP data were drawn contralaterally from CP4 and C4, respectively, which overlay the somatosensory cortex contralateral to tactile stimulation (Figure 4). CP3 was collected to visually inspect that there was lateralization of the P50/N70. The P100 and N140 ERPs occur bilaterally in the secondary somatosensory cortex (SII) and posterior parietal areas, respectively (Hämäläinen et al., 1990; see Figure 4); thus, data was collected from FCz and Cz. The P100, which was maximal at Cz, is thought to be initiated on the posterior parietal scalp contralateral to tactile stimulation and project ipsilaterally and frontally (Desmedt & Tomberg, 1989). For

this reason, data was also collected from P4. The N140 potentials, which were maximal at FCz, typically occur maximally contralaterally frontally and project bilaterally and posteriorly (Desmedt & Tomberg, 1989).

In contrast, early visually-evoked ERP components, the P1, N1, and P2 are evoked more posteriorly in the occipital lobe which houses the visual cortex (Arroyo, Lesser, Poon, Webber, & Gordon, 1997; Hillyard & Anllo-Vento, 1998). Unlike the early and mid-latency ERP components, the visual P3 is thought to arise from multiple generators (Hermann & Knight, 2001). The visual P3 can be further separated into an earlier, frontally generated P3a and later P3b, which arises from parietal areas. The P3 and its subcomponents (P3a and P3b) are often explored in tasks involving an unexpected stimulus, such as the oddball task (Herrmann & Knight, 2001). The P3a, known as the "novelty P3", occurs in response to novel stimuli, while stimulus categorization is reflected by the P3b or "target P3" (Hermann & Knight, 2001). In this study, the parietal target P3 (P3b) was more of interest than the novelty P3 (P3a) due to this thesis' focus on attentional orientation rather than perceptual salience of the visual stimuli. Though the exact generators of the target P3 are not yet known, there is evidence to support the contribution of multiple areas to P3b generation including the thalamus, temporal lobe, hippocampus/parahippocampal areas, and the insula (Hermann & Knight, 2001). To capture visual ERPs, data were collected from the occipital electrodes (Oz, O2, and O1) and the central parietal electrode (Pz).

Each exposure to a trial was epoched to stimulus events and were 500-milliseconds in duration. Epochs were set 100 milliseconds prior to stimulus onset and 400 milliseconds afterwards. Furthermore, epochs were baseline corrected to the prestimulus period (-100 to 0 ms).

Peak ERP amplitudes were measured from the electrode that evoked the largest peak amplitude for a given ERP component in the group grand averaged waveforms.When possible, potentials were calculated as peak-to-peak amplitudes between the ERP of interest and the preceding potential of the opposite polarity. Thus, P50, P100, P1, and P3 amplitudes were measured relative to the raw baseline-

corrected prestimulus voltage; however, N70, N140, N1, and P2 were calculated as the voltage relative to their preceding potential. Peak-to-peak amplitude differences of these ERP complexes were calculated and used in analysis, as these ERP components do not occur in isolation: P50-N70 (N70 amplitude), P100-N140 (N140 amplitude), P1-N1 (N1 amplitude), N1-P2 (P2 amplitude). All other metrics including P50, P100, P1, P3 amplitudes and all ERP latencies were extracted from the raw peak amplitudes. Each epoch was manually observed for noticeable artifacts that may have caused considerable noise, such as eye blinks or facial muscle flexion. These trials were marked and excluded in the final participant averages. Subjects not demonstrating the ERP or ERP complex within or around the specified timeframe were entered as a missing data point for that specific attentional condition of the ERP. Epochs were grand averaged for each stimulus type (T, Vd, TVd, Td, V, VTd).

2.5 Statistical Analysis

Objective 1

Statistical analyses were conducted using RStudio (version 2022.07.1.554; RStudio Team, 2022). Linear mixed models (LMMs) were run using the *lmerTest* package (version 3.1.3; Kuznetsova, Brockhoff, & Christensen, 2017) to determine the effects of trait anxiety and attention on ERP amplitudes and latencies in response to unimodal (visual or tactile) and bimodal (visual-tactile) stimuli. The simple LMM included trait anxiety (STAI-Y2 score) as a continuous fixed factor and subject number as a random factor. The complex model consisted of trait anxiety (STAI-Y2 score) and attention (toward vs. away) as fixed factors, with subject (i.e., participant number) as a random factor. Significance was calculated using *lmerTest*, which estimates degrees of freedom and generates p-values for mixed models using Satterthwaite's method. All analyses were set at a confidence interval of 95%. LMMs were fit by Residual Maximum Likelihood (REML) estimation. Analyses of Variance (ANOVAs) were conducted

between nested models (simple vs. complex) to determine whether the addition of attention as a categorical fixed factor (attend toward, attend away) significantly impacted the fit of the model. R^2 values were derived from the MuMIn package (R package version 1.46.0, Bartoń, 2022). Main effects and interactions were broken down post hoc by *emtrends* and *emmeans* in the emmeans package (version 1.7.5; Lenth, 2022) to extract linear marginal means of linear trends (trait anxiety) or to compare between conditions (attention), respectively. Inspection of Q-Q residual plots and residual scatterplots did not reveal any significant deviations from normality or homoscedasticity. No significant outliers were detected, and all ERP data was included in analysis. Effect sizes were interpreted based on standardized effect size magnitudes for ANOVAs performed on each of the LMMs: $0.01 \leq \eta_p^2 < 0.06$ (small effect), and $0.06 \leq \eta_p^2 < 0.14$ (medium effect), $0.14 \leq \eta_p^2$ (large effect) (Cohen, 1988). Only medium and large effects were discussed.

Objective 2

Linear mixed analysis was also performed on the subjects' behavioural response data to investigate the potential influences of trait anxiety on costs of tactile (with a visual stimulus) and visual (with a tactile stimulus) distractors to performance accuracy. Trait anxiety (STAI-Y2 score) and distractor cost for each sensory modality (visual distractor with a tactile stimulus vs. tactile distractor with a visual stimulus) were entered as fixed factors, while subjects were included as random factors. *rstatix* (version 0.7.0; Kassambara, 2012) was used to identify extreme points from each individuals' response data (Q1-3IQR and Q3+3IQR), which, in the rare case they were present, were flagged and removed prior to analysis. Following outlier removal, inspection of Q-Q residual plots and residual scatterplots did not reveal any significant deviations from normality or homoscedasticity. The LMMs were fit by Residual Maximum Likelihood (REML) estimation. The simple LMM included trait anxiety (STAI-Y2 score) as a continuous fixed factor and subject number as a random factor. The complex model consisted of trait

anxiety (STAI-Y2 score) and sensory modality as fixed factors, with subject (i.e., participant number) as a random factor. An Analysis of Variance (ANOVA) was conducted between the nested models (simple vs. complex) to determine whether the addition of sensory modality as a categorical fixed factor impacted the fit of the model. R^2 values were derived from the MuMIn package (R package version 1.46.0, Bartoń, 2022). False positive and negative responses in the behavioural data were removed to ensure that only correct responses were included for analysis. Distractor cost was calculated as:

$$100 - (\frac{\%\ ideal\ response\ during\ the\ distractor\ condition}{\%\ ideal\ response\ in\ undistracted\ condition} \times 100)$$

Effect sizes were interpreted based on standardized effect size magnitudes for an ANOVA performed on the LMM: $0.01 \leq \eta_p^2 < 0.06$ (small effect), and $0.06 \leq \eta_p^2 < 0.14$ (medium effect), $0.14 \leq \eta_p^2$ (large effect) (Cohen, 1988).

Chapter 3: Results

3.1 Effect of Trait Anxiety and Attention on the Tactile N70 ERP

Means and standard deviations of N70 amplitudes and latencies in all tactile conditions are presented in Table 1 (total N70 $M_{amplitude}$ -3.96 ± *SD* 2.75 uV, $M_{latency}$ 78.65 ± *SD* 9.57 ms). Results for LMMs and ANOVAs between nested linear models for N70 visual ERP peak amplitudes relative to P50 and latencies are presented in Table 2 (see Figure 4 for a visualization of all tactile ERP peaks). ANOVAs indicated that attention did not improve the goodness of fit of the predictive model of N70 peak amplitude or latency in response to either unimodal or bimodal stimuli (Table 1), causing trait anxiety (STAI-Y2) to be the only fixed factor entered in all LMMs. Contrary to hypothesis 1, N70 amplitude was not predicted by trait anxiety (STAI-Y2 score) or attention in response to either unimodal ($t_{df} = -1.11_{19.94}$, $p = 0.28$, $\eta_p^2 = 0.06$) or bimodal stimuli ($t_{df} = -1.90_{19.70}$, $p = 0.07$, $\eta_p^2 = 0.16$), although it approached significance and showed a large negative relationship between trait anxiety and N70 amplitude in response to bimodal visual-tactile stimuli. Furthermore, although the effect of trait anxiety on N70 amplitude in response to unimodal stimuli did not reach significance, the calculated effect size was moderate.

N70 latencies in response to unimodal stimuli were not significantly predicted by anxiety or attention, however, the effect of trait anxiety also approached significance ($t_{df} = -1.89_{21.68}$, $p = 0.07$, $\eta_p^2 = 0.14$), with a large effect. Notably, a significantly large negative effect of trait anxiety on N70 latencies in response to bimodal stimuli was demonstrated ($t_{df} = -2.33_{21.31}$, $p = 0.03$, $\eta_p^2 = 0.20$), indicating that higher trait anxious individuals showed N70 peaks earlier than low anxious individuals regardless of whether instructed to attend toward or away from the stimulus (Figure 5). (For a within-subjects version of Figure 5, see Appendix I.)

		Attentional Instructions	
		Attend Toward Tactile (Away from Visual)	Attend Away from Tactile (Toward Visual)
Stimulus Type	Unimodal	(**T**) $M_{amplitude}$ -4.13 ± *SD* 2.80 uV $M_{latency}$ 78.87 ± *SD* 10.19 ms	(**Td**) $M_{amplitude}$ -3.84 ± *SD* 3.03 uV $M_{latency}$ 75.83 ± *SD* 8.79 ms
	Bimodal	(**TVd**) $M_{amplitude}$ -4.54 ± *SD* 2.74 uV $M_{latency}$ 80.26 ± *SD* 10.64 ms	(**VTd**) $M_{amplitude}$ -3.76 ± *SD* 2.57 uV $M_{latency}$ 80.00 ± *SD* 9.34 ms

Table 1. Mean ± standard deviation values of N70 amplitudes and latencies in all tactile conditions. N70 peak amplitude was measured at C4, the electrode evoking the highest N70 magnitude in microVolts (uV), relative to the preceding peak of the opposite polarity (P50). Latency values represent the peak timing of the N70 following tactile stimulus onset (ms) at C4.

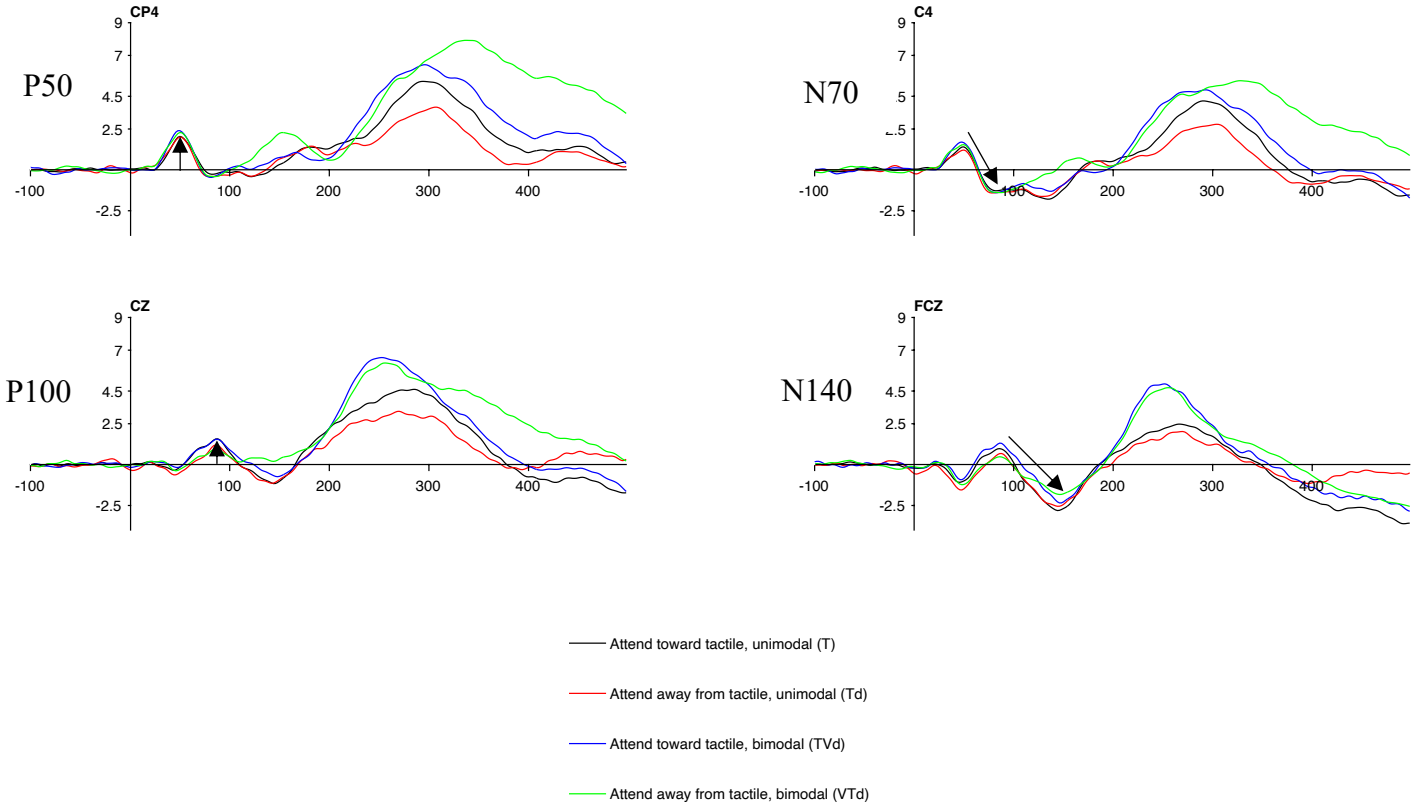

Figure 4. Grand averaged event-related potentials (ERPs) in response to tactile stimuli. The electrodes shown are where the tactile ERPs were reflected maximally and measured for analysis: P50 at CP4, N70 (relative to P50) at C4, P100 at Cz, and N140 (relative to P100) at FCz. The x-axes represent time (ms) relative to stimulus onset. The y-axes represent voltage baseline corrected to the pre-stimulus period (μV). Black arrows depict approximations of peak amplitude measurements for the labelled ERP.

	Stimulus Type	Predictor	Estimate	*SE*	*t*-value$_{df}$	LMM p-value	η^2 (partial)	ANOVA Results & R^2s
N70 Amplitude	Unimodal	(Intercept)	6.69	2.56	$2.61_{19.96}$	0.02	-	$\chi^2(2) = 0.50$ $p = 0.78$ $R^2m_1 = 0.05$ $R^2c_1 = 0.91$ $R^2m_2 = 0.05$ $R^2c_2 = 0.91$
		STAI-Y2	-0.07	0.06	$-1.11_{19.94}$	0.28	0.06	
	Bimodal	(Intercept)	8.09	2.12	$3.82_{19.93}$	0.001	-	$\chi^2(2) = 1.85$ $p = 0.40$ $R^2m_1 = 0.13$ $R^2c_1 = 0.74$ $R^2m_2 = 0.14$ $R^2c_2 = 0.73$
		STAI-Y2	-0.10	0.05	$-1.90_{19.70}$	0.07*	0.16	
N70 Latency	Unimodal	(Intercept)	-91.12	7.56	$12.05_{21.73}$	<0.001	-	$\chi^2(2) = 5.58$ $p = 0.06$* $R^2m_1 = 0.12$ $R^2c_1 = 0.74$ $R^2m_2 = 0.15$ $R^2c_2 = 0.77$
		STAI-Y2	-0.34	0.18	$-1.89_{21.68}$	0.07*	0.14	
	Bimodal	(Intercept)	96.83	7.47	$12.96_{21.57}$	<0.001	-	$\chi^2(2) = 0.08$ $p = 0.96$ $R^2m_1 = 0.17$ $R^2c_1 = 0.70$ $R^2m_2 = 0.16$ $R^2c_2 = 0.67$
		STAI-Y2	**-0.41**	**0.18**	**$-2.33_{21.31}$**	**0.03****	**0.20**	

Table 2. Results of linear mixed analysis to test the effects of trait anxiety (STAI-Y2 score) and attention (toward, away) on peak amplitude and latency of the N70 tactile ERP for unimodal (T, Td) and bimodal (TVd, VTd) stimuli. Attention as a fixed factor did not significantly improve the goodness of fit of the models (all ANOVA $p > 0.05$) and was omitted from the final N70 LMMs. R^2 values considering fixed factor(s) alone (R^2m) and after accounting for the random of subject (R^2c) are presented for the simple LMM (STAI-Y2; R^2m_1 & R^2c_1) and complex LMM (STAI-Y2 & sensory modality; R^2m_2 & R^2c_2). Significant predictors are shown in bold. **$p < 0.05$, *$p < 0.1$

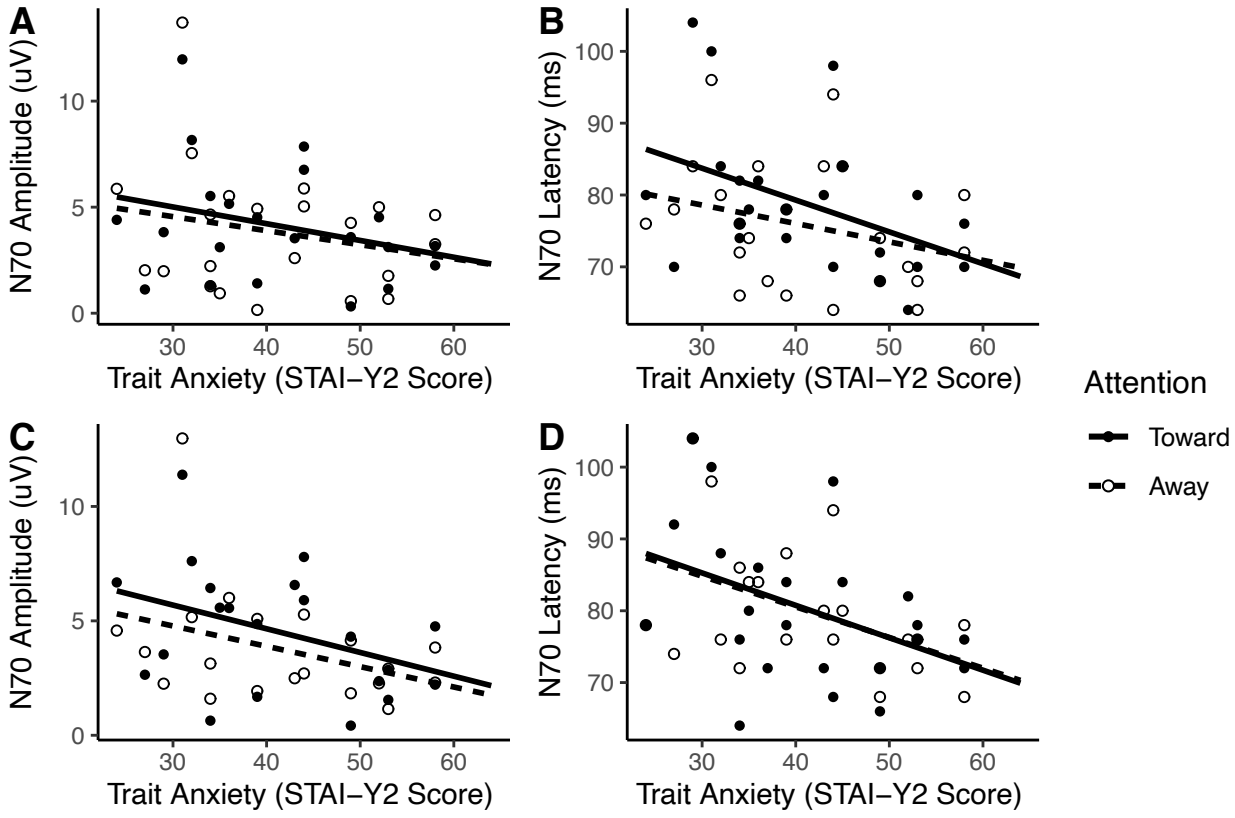

Figure 5. Effect of trait anxiety (STAI-Y2 score) and attention (toward, away) on tactile N70 peak amplitudes and latencies. A. N70 amplitudes in response to unimodal tactile stimuli. B. N70 latencies in response to unimodal tactile stimuli. C. N70 amplitudes in response to bimodal visual-tactile stimuli. D. N70 latencies in response to bimodal visual-tactile stimuli. A strong, significantly negative relationship between trait anxiety and N70 peak latency in the bimodal condition was observed, indicating that high trait anxious individuals showed faster tactile N70 latencies than less anxious individuals after exposure to visual-tactile stimuli regardless of attentional manipulation.

3.2 Exploratory Analysis of Early Visual & Tactile ERPs

Tactile ERPs

P50

Means and standard deviations of P50 amplitudes and latencies in all tactile conditions are presented in Table 3 (total P50 $M_{amplitude}$ 2.82 ± *SD* 1.93 uV, $M_{latency}$ 52.89 ± *SD* 6.68 ms). Results for LMMs and ANOVAs between nested linear models for P50 tactile ERP peak amplitudes and latencies are presented in Table 4. P50 amplitude was not predicted by trait anxiety (STAI-Y2 score) or attention in response to neither unimodal ($t_{df} = 0.06_{23.01}$, $p = 0.95$, $\eta_p^2 < 0.01$) nor bimodal stimuli ($t_{df} = 0.44_{22.44}$, $p = 0.66$, $\eta_p^2 < 0.01$). P50 latencies also were not significantly predicted by anxiety or attention in response to unimodal ($t_{df} = -1.17_{23.07}$, $p = 0.26$, $\eta_p^2 = 0.06$) and bimodal ($t_{df} = -0.79_{21.11}$, $p = 0.44$, $\eta_p^2 = 0.03$) stimuli. Although the effect of trait anxiety on P50 latency in response to unimodal stimuli did not reach statistical significance, the observed effect size indicated a moderate negative effect.

		Attentional Instructions	
		Attend Toward Tactile (Away from Visual)	Attend Away from Tactile (Toward Visual)
Stimulus Type	Unimodal	(**T**) $M_{amplitude}$ 2.71 ± *SD* 1.81 uV $M_{latency}$ 54.08 ± *SD* 8.56 ms	(**Td**) $M_{amplitude}$ 2.48 ± *SD* 2.00 uV $M_{latency}$ 52.40 ± *SD* 5.74 ms
	Bimodal	(**TVd**) $M_{amplitude}$ 3.10 ± *SD* 1.92 uV $M_{latency}$ 52.33 ± *SD* 6.77 ms	(**VTd**) $M_{amplitude}$ 3.00 ± *SD* 2.06 uV $M_{latency}$ 52.75 ± *SD* 5.53 ms

Table 3. Mean ± standard deviation values of P50 amplitudes and latencies in all tactile conditions. P50 peak amplitude was measured at CP4, the electrode evoking the highest P50 magnitude in microVolts (uV), relative to the baseline pre-stimulus period (-100 to 0 ms). Latency values represent the peak timing of the P50 following tactile stimulus onset (ms) at CP4.

	Stimulus Type	Predictor	Estimate	*SE*	*t*-value$_{df}$	LMM p-value	η^2 (partial)	ANOVA Results & R^2s
P50 Amplitude	Unimodal	(Intercept)	2.49	1.48	$1.68_{23.06}$	0.11	-	$\chi^2(2) = 0.74$ $p = 0.69$ $R^2m_1 = 0.00$ $R^2c_1 = 0.82$ $R^2m_2 = 0.00$ $R^2c_2 = 0.82$
		STAI-Y2	0.002	0.03	$0.06_{23.01}$	0.95	< 0.01	
	Bimodal	(Intercept)	2.33	1.51	$1.54_{22.56}$	0.137	-	$\chi^2(2) = 0.11$ $p = 0.95$ $R^2m_1 = 0.01$ $R^2c_1 = 0.73$ $R^2m_2 = 0.01$ $R^2c_2 = 0.71$
		STAI-Y2	0.02	0.04	$0.44_{22.44}$	0.66	< 0.01	
P50 Latency	Unimodal	(Intercept)	59.07	5.20	$11.37_{23.17}$	< 0.001	-	$\chi^2(2) = 1.82$ $p = 0.40$ $R^2m_1 = 0.04$ $R^2c_1 = 0.64$ $R^2m_2 = 0.06$ $R^2c_2 = 0.64$
		STAI-Y2	-0.14	0.12	$-1.17_{23.07}$	0.26	0.06	
	Bimodal	(Intercept)	55.89	4.27	$13.08_{22.31}$	< 0.001	-	$\chi^2(2) = 0.13$ $p = 0.94$ $R^2m_1 = 0.02$ $R^2c_1 = 0.49$ $R^2m_2 = 0.02$ $R^2c_2 = 0.46$
		STAI-Y2	-0.08	0.10	$-0.79_{21.11}$	0.44	0.03	

Table 4. Results of linear mixed analysis to test the effects of Trait Anxiety (STAI-Y2 score) and Attention (toward, away) on peak amplitude and latency of the P50 tactile ERP for unimodal (T, Td) and bimodal (TVd, VTd) stimuli. Attention as a fixed factor did not significantly improve the goodness of fit of the models (all ANOVA $p > 0.05$) and was omitted from the final P50 LMMs. R^2 values considering fixed factor(s) alone (R^2m) and after accounting for the random of subject (R^2c) are presented for the simple LMM (STAI-Y2; R^2m_1 & R^2c_1) and complex LMM (STAI-Y2 & sensory modality; R^2m_2 & R^2c_2).

P100

Means and standard deviations of P100 amplitudes and latencies in all tactile conditions are presented in Table 5 (total P100 $M_{amplitude}$ 2.08 ± *SD* 1.95 uV, $M_{latency}$ 97.74 ± *SD* 22.96 ms). Results for LMMs and ANOVAs between nested linear models for P100 tactile ERP peak amplitudes and latencies are presented in Table 6. P100 amplitude was not predicted by trait anxiety (STAI-Y2 score) or attention in response to neither unimodal ($t_{df} = -0.47_{25.34}$, $p = 0.64$, $\eta_p^2 < 0.01$) nor bimodal stimuli ($t_{df} = 0.37_{23.74}$, $p = 0.72$, $\eta^2_p < 0.01$). P100 latencies also were not significantly predicted by anxiety or attention in response to unimodal ($t_{df} = 0.53_{24.47}$, $p = 0.60$, $\eta^2_p = 0.01$) and bimodal ($t_{df} = 0.01_{24.02}$, $p = 1.00$, $\eta^2_p < 0.01$) stimuli.

		Attentional Instructions	
		Attend Toward Tactile (Away from Visual)	Attend Away from Tactile (Toward Visual)
Stimulus Type	Unimodal	(**T**) $M_{amplitude}$ 2.17 ± *SD* 1.94 uV $M_{latency}$ 97.92 ± *SD* 22.50 ms	(**Td**) $M_{amplitude}$ 1.74 ± *SD* 1.48 uV $M_{latency}$ 98.00 ± *SD* 23.28 ms
	Bimodal	(**TVd**) $M_{amplitude}$ 2.22 ± *SD* 2.08 uV $M_{latency}$ 97.00 ± *SD* 21.36 ms	(**VTd**) $M_{amplitude}$ 2.20 ± *SD* 2.32 uV $M_{latency}$ 98.08 ± *SD* 26.03 ms

Table 5. Mean ± standard deviation values of P100 amplitudes and latencies in all tactile conditions. P100 peak amplitude was measured at Cz, the electrode evoking the highest P100 magnitude in microVolts (uV), relative to the baseline pre-stimulus period (-100 to 0 ms). Latency values represent the peak timing of the P100 following tactile stimulus onset (ms) at Cz.

	Stimulus Type	Predictor	Estimate	*SE*	*t*-value$_{df}$	LMM p-value	η^2 (partial)	ANOVA Results & R^2s
P100 Amplitude	Unimodal	(Intercept)	2.54	1.27	$2.00_{24.97}$	0.06	-	$\chi^2(2) = 2.51$ $p = 0.28$ $R^2m_1 = 0.01$ $R^2c_1 = 0.63$ $R^2m_2 = 0.02$ $R^2c_2 = 0.65$
		STAI-Y2	-0.01	0.03	$-0.47_{25.34}$	0.64	< 0.01	
	Bimodal	(Intercept)	1.58	1.62	$0.97_{23.85}$	0.34	-	$\chi^2(2) = 0.24$ $p = 0.89$ $R^2m_1 = 0.00$ $R^2c_1 = 0.67$ $R^2m_2 = 0.01$ $R^2c_2 = 0.65$
		STAI-Y2	0.01	0.04	$0.37_{23.74}$	0.72	< 0.01	
P100 Latency	Unimodal	(Intercept)	88.53	17.88	$4.95_{24.33}$	< 0.001	-	$\chi^2(2) = 2.17$ $p = 0.34$ $R^2m_1 = 0.01$ $R^2c_1 = 0.88$ $R^2m_2 = 0.02$ $R^2c_2 = 0.87$
		STAI-Y2	0.22	0.42	$0.53_{24.47}$	0.60	0.01	
	Bimodal	(Intercept)	97.35	18.66	$5.22_{24.05}$	< 0.001	-	$\chi^2(2) = 2.31$ $p = 0.32$ $R^2m_1 = 0.00$ $R^2c_1 = 0.91$ $R^2m_2 = 0.00$ $R^2c_2 = 0.91$
		STAI-Y2	0.003	0.44	$0.01_{24.02}$	1.00	< 0.01	

Table 6. Results of linear mixed analysis to test the effects of Trait Anxiety (STAI-Y2 score) and Attention (toward, away) on peak amplitude and latency of the P100 tactile ERP for unimodal (T, Td) and bimodal (TVd, VTd) stimuli. Attention as a fixed factor did not significantly improve the goodness of fit of the models (all ANOVA $p > 0.05$) and was omitted from the final P100 LMMs. R^2 values considering fixed factor(s) alone (R^2m) and after accounting for the random of subject (R^2c) are presented for the simple LMM (STAI-Y2; R^2m_1 & R^2c_1) and complex LMM (STAI-Y2 & sensory modality; R^2m_2 & R^2c_2).

N140

Means and standard deviations of N140 amplitudes and latencies in all tactile conditions are presented in Table 7 (total N140 $M_{amplitude}$ -5.49 ± *SD* 3.77 uV, $M_{latency}$ 141.47 ± *SD* 24.13 ms). Results for LMMs and ANOVAs between nested linear models for N140 tactile ERP peak amplitudes relative to P100 and latencies are presented in Table 8. N140 amplitude was not predicted by trait anxiety (STAI-Y2 score) or attention in response to neither unimodal ($t_{df} = -0.60_{23.67}$, $p = 0.56$, $\eta_p^2 = 0.01$) nor bimodal stimuli ($t_{df} = -0.92_{23.97}$, $p = 0.37$, $\eta^2_p = 0.03$). N140 latencies also were not significantly predicted by anxiety or attention in response to unimodal ($t_{df} = 0.15_{24.00}$, $p = 0.88$, $\eta^2_p < 0.01$) and bimodal ($t_{df} = -0.23_{24.02}$, $p = 0.82$, $\eta^2_p < 0.01$) stimuli.

		Attentional Instructions	
		Attend Toward Tactile (Away from Visual)	Attend Away from Tactile (Toward Visual)
Stimulus Type	Unimodal	(**T**) $M_{amplitude}$ -6.03 ± *SD* 3.63 uV $M_{latency}$ 141.68 ± *SD* 21.86 ms	(**Td**) $M_{amplitude}$ -5.06 ± *SD* 3.66 uV $M_{latency}$ 142.31 ± *SD* 23.61 ms
	Bimodal	(**TVd**) $M_{amplitude}$ -5.73 ± *SD* 4.11 uV $M_{latency}$ 141.85 ± *SD* 23.70 ms	(**VTd**) $M_{amplitude}$ -5.09 ± *SD* 3.79 uV $M_{latency}$ 139.92 ± *SD* 28.51 ms

Table 7. Mean ± standard deviation values of N140 amplitudes and latencies in all tactile conditions. N140 peak amplitude was measured at FCz, the electrode evoking the highest N140 magnitude in microVolts (uV), relative to the preceding peak of the opposite polarity (P100). Latency values represent the peak timing of the N140 following tactile stimulus onset (ms) at FCz.

	Stimulus Type	Predictor	Estimate	*SE*	*t*-value$_{df}$	LMM p-value	η^2 (partial)	ANOVA Results & R^2s
N140 Amplitude	Unimodal	(Intercept)	7.00	2.92	$2.40_{23.75}$	0.02	-	$\chi^2(2) = 5.63$ $p = 0.06$* $R^2m_1 = 0.01$ $R^2c_1 = 0.88$ $R^2m_2 = 0.03$ $R^2c_2 = 0.89$
		STAI-Y2	-0.04	0.07	$-0.60_{23.67}$	0.56	0.01	
	Bimodal	(Intercept)	8.00	3.02	$2.65_{24.15}$	0.01	-	$\chi^2(2) = 4.78$ $p = 0.09$* $R^2m_1 = 0.03$ $R^2c_1 = 0.83$ $R^2m_2 = 0.04$ $R^2c_2 = 0.86$
		STAI-Y2	-0.06	0.07	$-0.92_{23.97}$	0.37	0.03	
N140 Latency	Unimodal	(Intercept)	139.61	18.00	$7.76_{24.02}$	< 0.001	-	$\chi^2(2) = 1.90$ $p = 0.39$ $R^2m_1 = 0.00$ $R^2c_1 = 0.91$ $R^2m_2 = 0.00$ $R^2c_2 = 0.91$
		STAI-Y2	0.06	0.42	$0.15_{24.00}$	0.88	< 0.01	
	Bimodal	(Intercept)	146.23	20.67	$7.07_{24.08}$	< 0.001	-	$\chi^2(2) = 0.07$ $p = 0.96$ $R^2m_1 = 0.00$ $R^2c_1 = 0.91$ $R^2m_2 = 0.00$ $R^2c_2 = 0.91$
		STAI-Y2	-0.11	0.49	$-0.23_{24.02}$	0.82	< 0.01	

Table 8. Results of linear mixed analysis to test the effects of Trait Anxiety (STAI-Y2 score) and Attention (toward, away) on peak amplitude and latency of the N140 tactile ERP for unimodal (T, Td) and bimodal (TVd, VTd) stimuli. Attention as a fixed factor did not significantly improve the goodness of fit of the models (all ANOVA $p > 0.05$) and was omitted from the final N140 LMMs. R^2 values considering fixed factor(s) alone (R^2m) and after accounting for the random of subject (R^2c) are presented for the simple LMM (STAI-Y2; R^2m_1 & R^2c_1) and complex LMM (STAI-Y2 & sensory modality; R^2m_2 & R^2c_2). *$p < 0.1$

Visual ERPs

P1

Means and standard deviations of P1 amplitudes and latencies in all visual conditions are presented in Table 9 (total P1 $M_{amplitude}$ 3.59 ± *SD* 3.54 uV, $M_{latency}$ 151.27 ± *SD* 21.05 ms). Results for LMMs and ANOVAs between nested linear models for P1 visual ERP peak amplitudes and latencies are presented in Table 10 (see Figure 6 for a visualization of all visual ERP peaks). P1 amplitude was not predicted by trait anxiety (STAI-Y2 score) or attention in response to neither unimodal ($t_{df} = 0.11_{23.43}$, $p = 0.91$, $\eta_p^2 < 0.01$) nor bimodal stimuli ($t_{df} = 1.03_{22.80}$, $p = 0.31$, $\eta^2_p = 0.04$). P100 latencies also were not significantly predicted by anxiety or attention in response to unimodal ($t_{df} = -0.26_{24.73}$, $p = 0.80$, $\eta^2_p < 0.01$) and bimodal ($t_{df} = 1.57_{23.63}$, $p = 0.13$, $\eta^2_p = 0.09$) stimuli. Although the effect of trait anxiety on P1 latency in response to bimodal stimuli did not reach statistical significance, the observed effect size indicated a moderate positive effect.

		Attentional Instructions	
		Attend Toward Visual (Away from Tactile)	Attend Away from Visual (Toward Tactile)
Stimulus Type	Unimodal	(**V**) $M_{amplitude}$ 2.49 ± *SD* 2.49 uV $M_{latency}$ 149.04 ± *SD* 20.63 ms	(**Vd**) $M_{amplitude}$ 1.43 ± *SD* 1.80 uV $M_{latency}$ 155.42 ± *SD* 22.13 ms
	Bimodal	(**VTd**) $M_{amplitude}$ 5.74 ± *SD* 3.74 uV $M_{latency}$ 148.92 ± *SD* 16.19 ms	(**TVd**) $M_{amplitude}$ 4.61 ± *SD* 3.85 uV $M_{latency}$ 151.17 ± *SD* 23.55 ms

Table 9. Mean ± standard deviation values of P1 amplitudes and latencies in all visual conditions. P1 peak amplitude was measured at Pz, the electrode evoking the highest P1 magnitude in microVolts (uV), relative to the baseline pre-stimulus period (-100 to 0 ms). Latency values represent the peak timing of the P1 following visual stimulus onset (ms) at Pz.

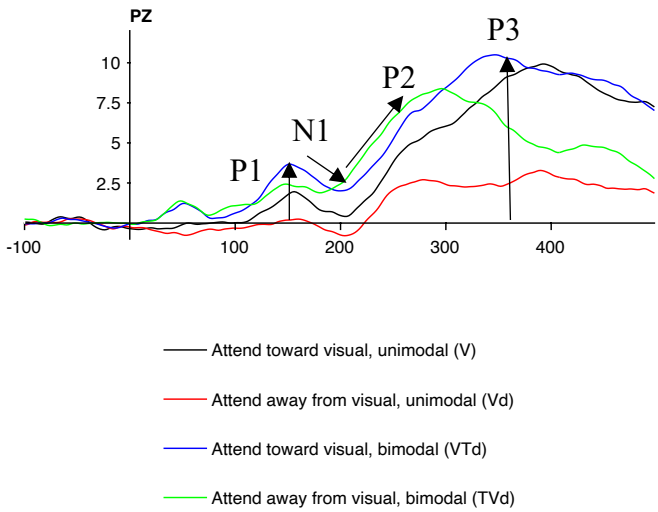

Figure 6. Grand averaged event-related potentials (ERPs) in response to visual stimuli. All visual ERPs were maximal at electrode Pz. The x-axis represents time (ms) relative to stimulus onset. The y-axis represents voltage baseline corrected to the pre-stimulus period (uV). Black arrows depict approximations of peak amplitude measurements for the labelled ERP.

	Stimulus Type	Predictor	Estimate	*SE*	*t*-value$_{df}$	LMM p-value	η^2 (partial)	ANOVA Results & R^2s
P1 Amplitude	Unimodal	(Intercept)	1.76	1.60	$1.11_{23.63}$	0.28	-	$\chi^2(2) = 4.65$ $p = 0.098$* $R^2m_1 = 0.00$ $R^2c_1 = 0.42$ $R^2m_2 = 0.06$ $R^2c_2 = 0.47$
		STAI-Y2	0.004	0.04	$0.11_{23.43}$	0.91	< 0.01	
	Bimodal	(Intercept)	1.83	3.13	$0.59_{22.93}$	0.57	-	$\chi^2(2) = 2.80$ $p = 0.25$ $R^2m_1 = 0.04$ $R^2c_1 = 0.84$ $R^2m_2 = 0.05$ $R^2c_2 = 0.84$
		STAI-Y2	0.07	0.07	$1.03_{22.80}$	0.31	0.04	
P1 Latency	Unimodal	(Intercept)	156.71	15.93	$9.84_{24.89}$	< 0.001	-	$\chi^2(2) = 2.93$ $p = 0.23$ $R^2m_1 = 0.00$ $R^2c_1 = 0.59$ $R^2m_2 = 0.03$ $R^2c_2 = 0.61$
		STAI-Y2	-0.10	0.37	$-0.26_{24.73}$	0.80	< 0.01	
	Bimodal	(Intercept)	127.33	14.59	$8.73_{23.96}$	< 0.001	-	$\chi^2(2) = 8.49$ $p = 0.01$** $R^2m_1 = 0.07$ $R^2c_1 = 0.54$ $R^2m_2 = 0.09$ $R^2c_2 = 0.54$
		STAI-Y2	0.53	0.34	$1.57_{23.63}$	0.13	0.09	

Table 10. Results of linear mixed analysis to test the effects of trait anxiety (STAI-Y2 score) and attention (toward, away) on peak amplitude and latency of the P1 visual ERP for unimodal (V, Vd) and bimodal (VTd, TVd) stimuli. Attention as a fixed factor did not significantly improve the goodness of fit of the models (all ANOVA $p > 0.05$) and was omitted from the final P1 LMMs. R^2 values considering fixed factor(s) alone (R^2m) and after accounting for the random of subject (R^2c) are presented for the simple LMM (STAI-Y2; R^2m_1 & R^2c_1) and complex LMM (STAI-Y2 & sensory modality; R^2m_2 & R^2c_2). *$p < 0.1$

N1

Means and standard deviations of N1 amplitudes and latencies in all visual conditions are presented in Table 11 (total N1 $M_{amplitude}$ -4.29 ± *SD* 2.98 uV, $M_{latency}$ 204.79 ± *SD* 28.32 ms). Results for LMMs and ANOVAs between nested linear models for N1 visual ERP peak amplitudes relative to P1 and latencies are presented in Table 12. N1 amplitude was not predicted by trait anxiety (STAI-Y2 score) or attention in response to neither unimodal ($t_{df} = -1.53_{22.94}$, $p = 0.14$, $\eta_p^2 = 0.09$) nor bimodal stimuli (STAI-Y2 score: $t_{df} = -1.31_{22.38}$, $p = 0.20$, $\eta^2_p = 0.07$; attention: $t_{df} = -0.13_{20.12}$, $p = 0.90$, $\eta^2_p < 0.01$). N1 latencies also were not significantly predicted by anxiety or attention in response to unimodal ($t_{df} = -0.76_{24.46}$, $p = 0.14$, $\eta^2_p = 0.09$) and bimodal ($t_{df} = -0.71_{22.66}$, $p = 0.48$, $\eta^2_p = 0.02$) stimuli. Despite a lack of significance, there was a moderate negative main effect of trait anxiety on N1 amplitude and latency in response to unimodal stimuli, as well as amplitude in response to bimodal stimuli.

		Attentional Instructions	
		Attend Toward Visual (Away from Tactile)	Attend Away from Visual (Toward Tactile)
Stimulus Type	Unimodal	(**V**) $M_{amplitude}$ -4.14 ± *SD* 3.33 uV $M_{latency}$ 203.33 ± *SD* 31.45 ms	(**Vd**) $M_{amplitude}$ -3.37 ± *SD* 2.41 uV $M_{latency}$ 202.32 ± *SD* 27.56 ms
	Bimodal	(**VTd**) $M_{amplitude}$ -5.72 ± *SD* 3.09 uV $M_{latency}$ 210.32 ± *SD* 26.02 ms	(**TVd**) $M_{amplitude}$ -3.93 ± *SD* 2.64 uV $M_{latency}$ 203.12 ± *SD* 29.08 ms

Table 11. Mean ± standard deviation values of N1 amplitudes and latencies in all tactile conditions. N1 peak amplitude was measured at Pz, the electrode evoking the highest N1 magnitude in microVolts (uV), relative to the preceding peak of the opposite polarity (P1). Latency values represent the peak timing of the N1 following tactile stimulus onset (ms) at Pz.

	Stimulus Type	Predictor	Estimate	*SE*	*t*-value$_{df}$	LMM p-value	η^2 (partial)	ANOVA Results & R^2s
N1 Amplitude	Unimodal	(Intercept)	6.74	2.09	$3.22_{22.99}$	< 0.001	-	$\chi^2(2) = 5.62$ $p = 0.06$* $R^2m_1 = 0.08$ $R^2c_1 = 0.64$ $R^2m_2 = 0.12$ $R^2c_2 = 0.71$
		STAI-Y2	-0.07	0.05	$-1.53_{22.94}$	0.14	0.09	
	Bimodal	(Intercept)	7.39	2.10	$3.52_{23.66}$	< 0.001	-	$\chi^2(2) = 10.85$ $p = 0.004$** $R^2m_1 = 0.05$ $R^2c_1 = 0.51$ $R^2m_2 = 0.14$ $R^2c_2 = 0.68$
		STAI-Y2	-0.06	0.05	$-1.31_{22.38}$	0.20	0.07	
		Attention	-0.20	1.55	$-0.13_{20.12}$	0.90	< 0.01	
		STAI-Y2*Attention	-0.03	0.04	$-0.75_{19.83}$	0.46	0.03	
N1 Latency	Unimodal	(Intercept)	220.32	22.64	$9.73_{24.34}$	< 0.001	-	$\chi^2(2) = 3.62$ $p = 0.16$ $R^2m_1 = 0.02$ $R^2c_1 = 0.51$ $R^2m_2 = 0.02$ $R^2c_2 = 0.51$
		STAI-Y2	-0.41	0.53	$-0.76_{24.46}$	0.14	0.09	
	Bimodal	(Intercept)	219.48	19.38	$11.33_{22.61}$	< 0.001	-	$\chi^2(2) = 1.44$ $p = 0.49$ $R^2m_1 = 0.02$ $R^2c_1 = 0.51$ $R^2m_2 = 0.03$ $R^2c_2 = 0.50$
		STAI-Y2	-0.32	0.45	$-0.71_{22.66}$	0.48	0.02	

Table 12. Results of linear mixed analysis to test the effects of Trait Anxiety (STAI-Y2 score) and Attention (toward, away) on peak amplitude and latency of the N1 visual ERP for unimodal (V, Vd) and bimodal (VTd, TVd) stimuli. Attention as a fixed factor significantly improved the goodness of fit of the model for N1 amplitude in response to bimodal stimuli (ANOVA $p < 0.05$) but did not for other models (other ANOVA $p > 0.05$). R^2 values considering fixed factor(s) alone (R^2m) and after accounting for the random of subject (R^2c) are presented for the simple LMM (STAI-Y2; R^2m_1 & R^2c_1) and complex LMM (STAI-Y2 & sensory modality; R^2m_2 & R^2c_2). **$p < 0.05$, *$p < 0.1$

P2

Means and standard deviations of P2 amplitudes and latencies in all visual conditions are presented in Table 13 (total P2 $M_{amplitude}$ 7.07 ± *SD* 4.03 uV, $M_{latency}$ 272.93 ± *SD* 22.43 ms). Results for LMMs and ANOVAs between nested linear models for P2 visual ERP peak amplitudes and latencies are presented in Table 14. P2 amplitude was not predicted by trait anxiety (STAI-Y2 score) ($t_{df} = -1.16_{22.51}$, $p = 0.26$, $\eta^2_p = 0.06$) or attention in response to unimodal visual stimuli; however, LMM analysis revealed a large significant interaction between trait anxiety and attention in the prediction of P2 amplitude in response to bimodal (visual-tactile) stimuli ($t_{df} = -2.17_{21.82}$, $p = 0.04$, $\eta^2_p = 0.18$). A *post hoc* contrast between levels of attention (toward vs. away) was not significant (Estimate = 0.93, *SE* = 0.54, $t_{df} = 1.73_{22.2}$, $p = 0.10$); however, a significant *post hoc* contrast between slopes of each level of attention in relation to STAI-Y2 score (Estimate = 0.11, *SE* = 0.05, $t_{df} = 2.16_{22.1}$, $p = 0.04$) indicated that while a slight negative relationship was observed between trait anxiety and P2 amplitude when attending toward bimodal (visual-tactile) stimuli (slope = -0.008, *SE* = -.082), a stronger negative relationship was observed between trait anxiety and P2 amplitude when attending toward bimodal (visual-tactile) stimuli (slope = -0.12, *SE* = -.081), see Figure 7. (For a within-subjects version of Figure 7, see Appendix I.) In sum, trait anxiety predicted a significant decline in visual P2 amplitude when attending away from a visual stimulus compared to when attending towards it. Lastly, P2 latencies were not significantly predicted by anxiety or attention in response to unimodal ($t_{df} = -1.18_{23.76}$, $p = 0.25$, $\eta^2_p = 0.06$) and bimodal (trait anxiety (STAI-Y2 score): $t_{df} = -0.11_{24.04}$, $p = 0.92$, $\eta^2_p < 0.01$; attention: $t_{df} = 0.02_{23.40}$, $p = 0.99$, $\eta^2_p < 0.01$) stimuli. While the effect of trait anxiety on P2 latency in response to unimodal stimuli did not reach statistical significance, the observed effect size indicated a moderate negative effect.

		Attentional Instructions	
		Attend Toward Visual (Away from Tactile)	Attend Away from Visual (Toward Tactile)
Stimulus Type	Unimodal	(**V**) $M_{amplitude}$ 6.97 ± *SD* 4.13 uV $M_{latency}$ 273.28 ± *SD* 23.72 ms	(**Vd**) $M_{amplitude}$ 5.56 ± *SD* 3.03 uV $M_{latency}$ 272.80 ± *SD* 19.10 ms
	Bimodal	(**VTd**) $M_{amplitude}$ 8.25 ± *SD* 4.21 uV $M_{latency}$ 278.32 ± *SD* 24.51 ms	(**TVd**) $M_{amplitude}$ 7.55 ± *SD* 4.39 uV $M_{latency}$ 267.54 ± *SD* 22.03 ms

Table 13. Mean ± standard deviation values of P2 amplitudes and latencies in all tactile conditions. P2 peak amplitude was measured at Pz, the electrode evoking the highest P2 magnitude in microVolts (uV), relative to the preceding peak of the opposite polarity (N1). Latency values represent the peak timing of the P2 following tactile stimulus onset (ms) at Pz.

	Stimulus Type	Predictor	Estimate	*SE*	*t*-value$_{df}$	LMM p-value	η^2 (partial)	ANOVA Results & R^2s
P2 Amplitude	Unimodal	(Intercept)	9.17	2.55	$3.59_{22.63}$	< 0.001	-	$\chi^2(2) = 5.40$ $p = 0.067$* $R^2m_1 = 0.04$ $R^2c_1 = 0.51$ $R^2m_2 = 0.09$ $R^2c_2 = 0.60$
		STAI-Y2	-0.07	0.06	$-1.16_{22.51}$	0.26	0.06	
	Bimodal	(Intercept)	10.59	3.30	$3.21_{22.69}$	0.004	-	$\chi^2(2) = 7.20$ $p = 0.03$** $R^2m_1 = 0.02$ $R^2c_1 = 0.78$ $R^2m_2 = 0.05$ $R^2c_2 = 0.82$
		STAI-Y2	-0.06	0.08	$-0.81_{22.63}$	0.43	0.03	
		Attention	2.51	1.51	$1.66_{21.87}$	0.11	0.11	
		STAI-Y2*Attention	**-0.08**	**0.04**	**$-2.17_{21.82}$**	**0.04****	**0.18**	
P2 Latency	Unimodal	(Intercept)	289.67	14.72	$19.68_{24.01}$	< 0.001	-	$\chi^2(2) = 0.35$ $p = 0.84$ $R^2m_1 = 0.04$ $R^2c_1 = 0.51$ $R^2m_2 = 0.04$ $R^2c_2 = 0.49$
		STAI-Y2	-0.41	0.34	$-1.18_{23.76}$	0.25	0.06	
	Bimodal	(Intercept)	274.82	17.48	$15.72_{24.11}$	< 0.001	-	$\chi^2(2) = 8.49$ $p = 0.01$** $R^2m_1 = 0.00$ $R^2c_1 = 0.64$ $R^2m_2 = 0.06$ $R^2c_2 = 0.73$
		STAI-Y2	-0.043	0.41	$-0.11_{24.04}$	0.92	< 0.01	
		Attention	0.19	10.20	$0.02_{23.40}$	0.99	< 0.01	
		STAI-Y2*Attention	-0.19	0.24	$-0.81_{23.32}$	0.43	0.03	

Table 14. Results of linear mixed analysis to test the effects of Trait Anxiety (STAI-Y2 score) and Attention (toward, away) on peak amplitude and latency of the P2 visual ERP for unimodal (V, Vd) and bimodal (VTd, TVd) stimuli. Attention as a fixed factor significantly improved the goodness of fit of the models for P2 amplitude and latency in response to bimodal stimuli (ANOVA $p < 0.05$) but not for unimodal stimuli (ANOVA $p > 0.05$). R^2 values considering fixed factor(s) alone (R^2m) and after accounting for the random of subject (R^2c) are presented for the simple LMM (STAI-Y2; R^2m_1 & R^2c_1) and complex LMM (STAI-Y2 & sensory modality; R^2m_2 & R^2c_2). Significant predictors are shown in bold. **$p < 0.05$, *$p < 0.01$

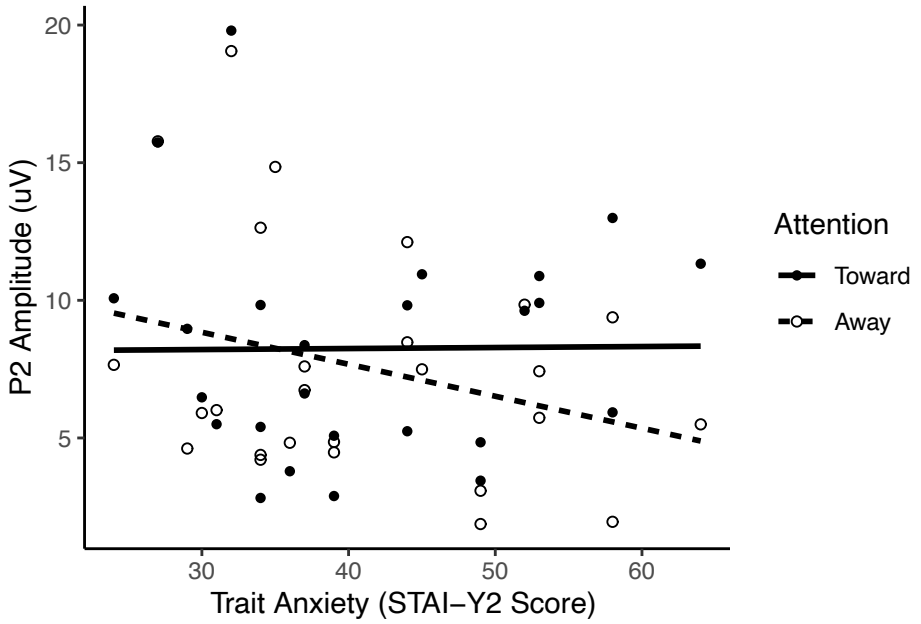

Figure 7. Trait anxiety and attention interaction of visual P2 ERP amplitudes in response to bimodal (visual-tactile) stimuli. Trait anxiety predicted a significant decline in P2 amplitude when diverting attention away from the visual component of a bimodal visual-tactile stimulus compared to when attending towards it.

P3

Means and standard deviations of P3 amplitudes and latencies in all visual conditions are presented in Table 15 (total P3 $M_{amplitude}$ 8.57 ± *SD* 5.89 uV, $M_{latency}$ 396.90 ± *SD* 47.20 ms). Results for LMMs and ANOVAs between nested linear models for P3 visual ERP peak amplitudes and latencies are presented in Table 16. While there was no significant effect of trait anxiety or attention on P3 amplitude in response to unimodal visual stimuli (trait anxiety: $t_{df} = 0.21_{24.00}$, $p = 0.84$, $\eta^2_p < 0.01$; attention: $t_{df} = -1.18_{24.00}$, $p = 0.25$, $\eta^2_p = 0.05$), attention ($t_{df} = -2.47_{24.00}$, $p = 0.02$, $\eta^2_p = 0.20$) was a significant predictor of P3 amplitude in response to bimodal visual-tactile stimuli. This large effect was broken down with a pairwise comparison between the two levels of attention (toward vs. away) which showed that when in response to a bimodal visual-tactile stimulus, P3 amplitude was significantly greater when attending toward the visual component of the stimulus ($M = 11.56 \pm SE$ 1.05 uV) than when attending away ($M = 7.57 \pm SE$ 1.05 uV) from the visual component (Estimate = 3.99, $SE = 0.61$, $t_{df} = 6.56_{24}$, $p < 0.001$; Figure Xc); see Figure 8. (For a within-subjects version of Figure 8, see Appendix I.) Although the effect of trait anxiety on P3 amplitude in response to bimodal stimuli did not reach statistical significance, the observed effect size indicated a moderate positive effect.

A significant main effect of attention, as well as an interaction between trait anxiety and attention were found, with large effects on P3 latency in response to unimodal visual stimuli (attention main effect: $t_{df} = 3.21_{24.00}$, $p = 0.004$, $\eta^2_p = 0.30$; trait anxiety (STAI-Y2)*attention interaction: $t_{df} = -3.13_{24.00}$, $p = 0.005$, $\eta^2_p = 0.29$). A *post hoc* contrast between levels of attention (toward vs. away) was not significant (Estimate = -5.38, $SE = 7.75$, $t_{df} = -0.70_{24}$, $p = 0.49$); however, a significant pairwise comparison between slopes of each level of attention in relation to STAI-Y2 score (Estimate = 2.23, $SE = 0.74$, $t_{df} = 3.13_{24}$, $p = 0.005$) indicated that while a positive relationship was observed between trait anxiety and P3 latency when attending toward unimodal visual stimuli (slope = 0.89, $SE = 0.78$), a negative relationship was observed between trait anxiety and P3 latency when attending away from unimodal

visual stimuli (slope = -1.43, *SE* = 0.78), see Figure 9. (For a within-subjects version of Figure 9, see Appendix I.) Thus, while attending toward a unimodal visual stimulus, P3 latency increased with higher trait anxiety, but P3 latency decreased with higher trait anxiety while diverting attention away. P3 latencies were not significantly predicted by trait anxiety in response to bimodal stimuli (t_{df} = -0.31$_{24.00}$, p = 0.76, η^2_p < 0.01) and attention did not contribute to the goodness of fit of this model, unlike for the other P3 LMMs (Table 8).

		Attentional Instructions	
		Attend Toward Visual (Away from Tactile)	Attend Away from Visual (Toward Tactile)
Stimulus Type	Unimodal	(**V**) $M_{amplitude}$ 10.95 ± *SD* 6.05 uV $M_{latency}$ 398.85 ± *SD* 40.04 ms	(**Vd**) $M_{amplitude}$ 4.22 ± *SD* 3.28 uV $M_{latency}$ 404.23 ± *SD* 45.14 ms
	Bimodal	(**VTd**) $M_{amplitude}$ 11.55 ± *SD* 5.94 uV $M_{latency}$ 387.31 ± *SD* 50.95 ms	(**TVd**) $M_{amplitude}$ 7.57 ± *SD* 4.91 uV $M_{latency}$ 397.23 ± *SD* 52.79 ms

Table 15. Mean ± standard deviation values of P3 amplitudes and latencies in all visual conditions. P3 peak amplitude was measured at Pz, the electrode evoking the highest P3 magnitude in microVolts (uV), relative to the baseline pre-stimulus period (-100 to 0 ms). Latency values represent the peak timing of the P3 following visual stimulus onset (ms) at Pz.

	Stimulus Type	Predictor	Estimate	*SE*	*t*-value$_{df}$	LMM p-value	η^2 (partial)	ANOVA Results & R^2s
P3 Amplitude	Unimodal	(Intercept)	6.91	3.28	$2.11_{24.00}$	0.05	-	$\chi^2(2) = 25.01$ $p < 0.001$** $R^2m_1 = 0.00$ $R^2c_1 = 0.00$ $R^2m_2 = 0.32$ $R^2c_2 = 0.57$
		STAI-Y2	0.02	0.08	$0.21_{24.00}$	0.84	< 0.01	
		Attention	-3.70	3.13	$-1.18_{24.00}$	0.25	0.05	
		STAI-Y2*Attention	-0.03	0.07	$-0.35_{24.00}$	0.73	< 0.01	
	Bimodal	(Intercept)	3.83	4.09	$0.94_{24.00}$	0.36	-	$\chi^2(2) = 27.02$ $p < 0.001$** $R^2m_1 = 0.06$ $R^2c_1 = 0.64$ $R^2m_2 = 0.18$ $R^2c_2 = 0.86$
		STAI-Y2	0.14	0.10	$1.45_{24.00}$	0.16	0.08	
		Attention	**-4.33**	**1.75**	**$-2.47_{24.00}$**	**0.02****	**0.20**	
		STAI-Y2*Attention	0.04	0.04	$0.90_{24.00}$	0.38	0.03	
P3 Latency	Unimodal	(Intercept)	412.74	29.21	$14.13_{24.00}$	< 0.001	-	$\chi^2(2) = 9.29$ $p = 0.010$** $R^2m_1 = 0.02$ $R^2c_1 = 0.02$ $R^2m_2 = 0.09$ $R^2c_2 = 0.59$
		STAI-Y2	-0.27	0.67	$-0.40_{24.00}$	0.69	< 0.01	
		Attention	**71.55**	**22.30**	**$3.21_{24.00}$**	**0.004****	**0.30**	
		STAI-Y2*Attention	**-1.64**	**0.52**	**$-3.13_{24.00}$**	**0.005****	**0.29**	
	Bimodal	(Intercept)	403.50	37.44	$10.78_{24.00}$	< 0.001	-	$\chi^2(2) = 1.92$ $p = 0.38$ $R^2m_1 = 0.00$ $R^2c_1 = 0.59$ $R^2m_2 = 0.02$ $R^2c_2 = 0.59$
		STAI-Y2	-0.27	0.88	$-0.31_{24.00}$	0.76	< 0.01	

Table 16. Results of linear mixed analysis to test the effects of Trait Anxiety (STAI-Y2 score) and Attention (Toward, Away) on peak amplitude and latency of the P3 visual ERP for unimodal (V, Vd) and bimodal (VTd, TVd) stimuli. Attention as a fixed factor significantly improved the goodness of fit of P3 amplitude and unimodal latency models (ANOVA $p < 0.05$), but not latency in response to bimodal stimuli (ANOVA $p > 0.05$). R^2 values considering fixed factor(s) alone (R^2m) and after accounting for the random of subject (R^2c) are presented for the simple LMM (STAI-Y2; R^2m_1 & R^2c_1) and complex LMM (STAI-Y2 & sensory modality; R^2m_2 & R^2c_2). Significant predictors are shown in bold. **$p < 0.05$, *$p < 0.01$

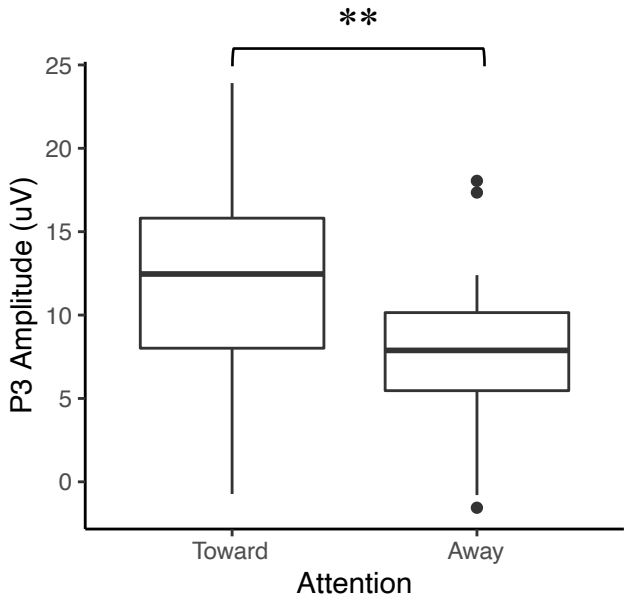

Figure 8. Significant effect of attention on visual P3 ERP amplitudes in response to bimodal visual-tactile stimuli. When diverting attention toward the visual component of the bimodal stimulus, P3 amplitudes were significantly larger than when attending away from the visual component (toward tactile). $^{**}p < 0.05$

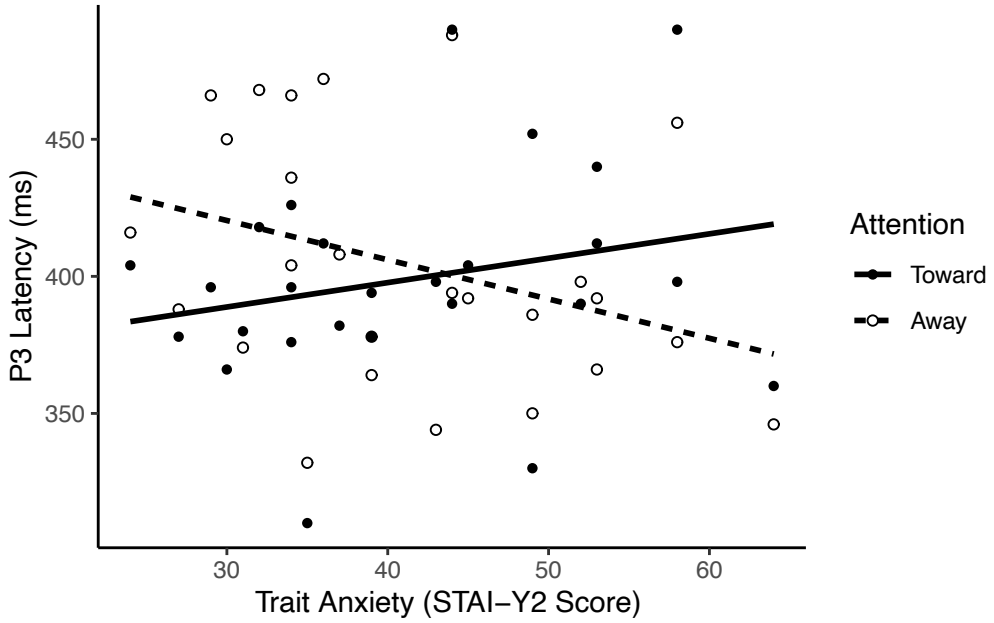

Figure 9. Trait anxiety and attention interaction of visual P3 ERP latencies in response to unimodal visual stimuli. A positive relationship was shown between trait anxiety and P3 latency while attending toward the visual stimulus, but a negative relationship was shown when attending away.

3.3 Distractor Cost to Behavioural Accuracy

	Predictor	Estimate	*SE*	t-value$_{df}$	LMM p-value	η2 (partial)	ANOVA Results & R^2s
Distractor Cost	(Intercept)	-2.71	3.90	$-0.70_{48.00}$	< 0.001	-	$\chi^2(2) = 26.52$ p < 0.001** $R^2m_1 = 0.02$ $R^2c_1 = 0.02$ $R^2m_2 = 0.40$ $R^2c_2 = 0.40$
	STAI-Y2	0.11	0.09	$-1.19_{48.00}$	0.24	0.03	
	Sensory modality	9.05	5.51	$-1.64_{48.00}$	0.11	0.05	
	STAI-Y2*Sensory modality	-0.03	0.13	$0.26_{48.00}$	0.79	< 0.01	

Table 17. Results of linear mixed analysis to test the effects of trait anxiety (STAI-Y2 score) and sensory modality (tactile with a visual distractor, visual with a tactile distractor) on the cost to accuracy of introducing a crossmodal distractor during the behavioural task. Sensory modality as a fixed factor significantly improved the goodness of fit of the model (ANOVA $p < 0.05$). R^2 values considering fixed factor(s) alone (R^2m) and after accounting for the random of subject (R^2c) are presented for the simple LMM (STAI-Y2; R^2m_1 & R^2c_1) and complex LMM (STAI-Y2 & sensory modality; R^2m_2 & R^2c_2). **$p < 0.05$

Results for linear mixed analyses on behavioural data are presented in Table 17 ($M_{\text{visual distractor, tactile stimulus}}$ -3.61 ± *SD* 6.26 uV, $M_{\text{tactile distractor, visual stimulus}}$ 7.19 ± *SD* 7.23 ms). No significant main effects of trait anxiety ($t_{df} = -1.19_{48.00}$, $p = 0.24$, $\eta^2_p = 0.03$) or sensory modality of the stimuli ($t_{df} = -1.64_{48.00}$, $p = 0.11$, $\eta^2_p = 0.05$) in relation to distractor cost values were observed (Figure 10).

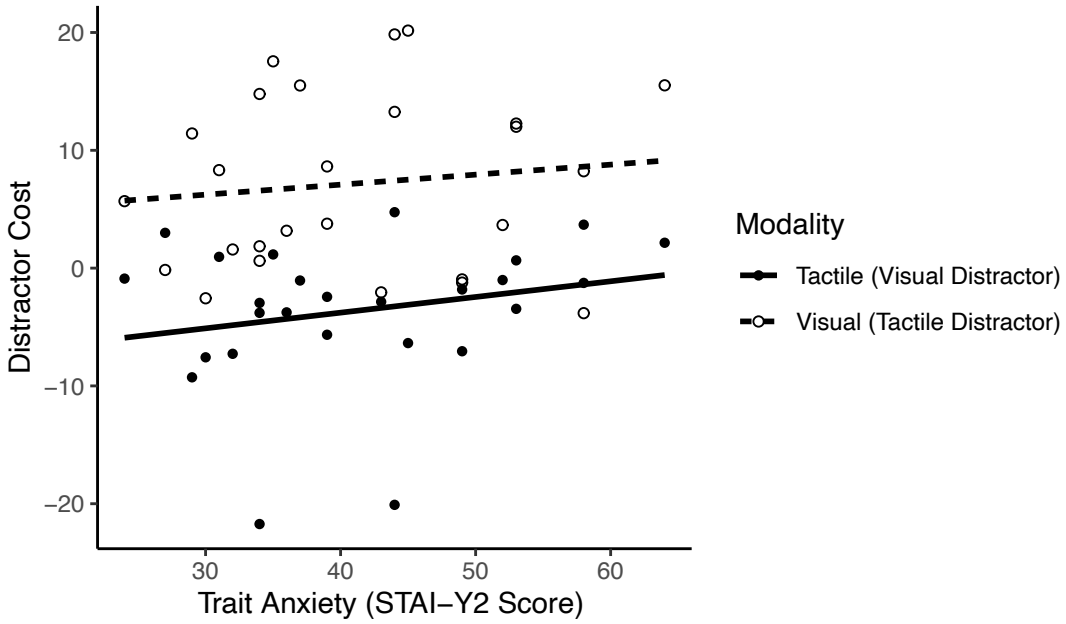

Figure 10. Relationship between trait anxiety and sensory modality on distractor cost. A regression line for the distractor cost of visual distractors with tactile stimuli is presented as a solid line, and tactile distractors with visual stimuli is presented as a dashed line. No significant relationship between trait anxiety or sensory modality on distractor cost was observed.

Chapter 4: Discussion

4.1 Summary

The current study aimed to determine whether trait anxiety influences neural correlates of sensory processing and attention, as well as whether the presence of a distractor differentially incurs a behavioural cost to accuracy in sensorimotor function based on trait anxiety. The primary hypothesis for this study was that the tactile N70 ERP would be modulated by trait anxiety, then secondarily, by task relevance. Trait anxiety (STAI-Y2 score) showed a strong negative relationship with tactile N70 latency when exposed to bimodal visual-tactile stimuli; however, this effect was not present in response to unimodal tactile stimuli. Although this effect of trait anxiety on N70 amplitude did not reach significance, there was a large effect that approached significance in response to bimodal stimuli and a moderate effect of trait anxiety in response to unimodal stimuli. In summary, trait anxiety showed large negative effects on N70 amplitudes (bimodal stimuli only) and latencies with a moderate effect on N70 amplitude in response to unimodal tactile stimuli. The manipulation of attention did not contribute to these relationships.

Exploratory analysis on other early to early-to-mid-latency tactile (P50, P100, N140) and early-to-late visual (P1, N1, P2, P3) ERPs indicated that trait anxiety did not significantly influence tactile ERPs but did so for visual ERPs. Notably, there was a significant interaction between trait anxiety and attention for the visual P2 in response to visual-tactile stimuli, as well as for P3 latency in response to unimodal visual stimuli. Some exploratory ERP effects were moderate and did not reach statistical significance but will be discussed below. In addition, trait anxiety did not significantly impact distractor cost of either stimulus type as hypothesized. Overall, as predicted, neural markers of sensory and attentional processing were modulated by trait anxiety; however, sensorimotor accuracy (as evaluated by distractor cost) was not.

4.2 Evidence for Modulation of the Tactile N70 ERP by Trait Anxiety

Regardless of attentional manipulation, higher trait anxiety trended toward or showed significantly smaller N70 amplitudes and faster N70 latencies. Results from the current study revealed a large negative effect of trait anxiety on N70 amplitudes (bimodal stimuli) and a moderate negative effect on N70 amplitude in response to unimodal tactile stimuli, although these did not reach significance. Importantly, a large negative effect of trait anxiety on N70 latencies was observed for both stimulus types; however, this effect only reached significance for bimodal stimuli. Possible factors leading to a lack of significant effects are discussed in Section 4.5: Limitations.

With regards to N70 amplitude, Adams et al. (2019) showed that temporary inhibition of the PFC with cTBS impacts the attentional modulation of the tactile N70 ERP. Their findings contributed to the understanding that the prefrontal cortex contributes to the sensory gating of information, wherein inhibition of the PFC with cTBS prevented a facilitation of N70 amplitude in response to attended tactile information that was observed pre-cTBS (Adams et al., 2019). In the present study, it was hypothesized ERP amplitudes relative to trait anxiety would show similar results to those following inhibition of the PFC. This hypothesis was based on prior research related to trait anxiety and dysregulated activity of the DLPFC (Basten et al., 2011, 2012; Forster et al., 2015; Morgenroth et al., 2019), a neural area necessary in sensory gating (Chao & Knight, 1995). Notably, the trends toward diminished N70 amplitude reflect similar results to those found by Adams et al. (2019), with smaller N70 amplitudes observed both with higher trait anxiety and following cTBS to the PFC. Thus, this result indicates that there may be a sign of altered underlying prefrontal cortical activity related to trait anxiety in the present study, which may have not been reflected behaviourally due to compensatory neural mechanisms.

Unlike the findings of Adams et al. (2017), there was no significant effect of attention on N70 amplitude when attending toward tactile compared to when attending toward the visual modality. It is

possible that the attentional effects were not strong enough to significantly contribute to the goodness of fit of the model due to the sample size (for more comments on factors that may have contributed to a lack of effects, see Section 4.5: Limitations).

N70 latency, which was shown to have a strong, significant negative relationship with trait anxiety in response to bimodal visual-tactile stimuli, may have revealed differences as a function of trait anxiety not related to increases or decreases in attention or prefrontal influences as in amplitude, but rather in systematic alterations in stimulus processing. Gazzaley, Cooney, McEvoy, Knight, and D'Esposito (2005) detailed how top-down attentional influences can impact not only the magnitude, but also the processing speed of ERPs. They propose that faster latency reflects more efficient processing and facilitation of extracting of relevant information (Gazzaley et al., 2005). As a result, these top-down processes can influence what gets selected in the case of competing sensory inputs (Gazzaley et al., 2005). In a task involving tactile spatial selection, Schubert et al. (2008) found that faster N80 (analogous to N70) latencies may be associated with increased task difficulty. Overall, the reduction in N70 latencies relative to trait anxiety may reflect more efficient extraction of tactile information based on Gazzaley et al.'s (2005) theory, but difficulty as well, based on Schubert et al.'s (2008) account. Furthermore, the presence of increased sensory load as a result of sensory conflict when exposed to bimodal stimuli in the current study may have brought out a stronger difference related to trait anxiety that was not present in response to unimodal tactile stimuli. It is possible that these effects may reflect a compensatory mechanism that is increased slightly in the presence of a simultaneous distractor and becomes magnified with higher trait anxiety.

The effects observed in N70 latency may also be connected to the LC-NE system. Lecas (2004) found that stimulation of the LC in rats resulted in temporal shortening of cortical tactile discharge and decreases in spike jitter, a reflection of variance in latency. They explained this heightened LC activity as "noradrenergic sharpening of thalamocortical processing" (Lecas, 2004).

The results shown by the tactile N70 in this study showed a similar pattern, with generally lower latencies with higher trait anxiety. Along with a decrease in latency whether significant (bimodal) or not (unimodal), there qualitatively appears to be less variance with increased anxiety between individuals upon observation of N70 plots, which is similar to Lecas's (2004) findings. Thus, this reflects possible heightened LC activity that can induce thalamocortical changes, which is not a new concept when considering the idea of hypervigilance. Although Lecas (2004) focused on the first spike in response to tactile stimulation and the N70 occurs later, it is possible that there are similar noradrenergic (NE) mechanisms at play.

4.3 Stimulus Relevance Plays a Role in Task-Related Processing Relative to Trait Anxiety

Visual P2 amplitude in response to visual-tactile stimuli is modulated by trait anxiety and attention

This study showed a negative relationship between trait anxiety and P2 amplitude when attending away from the visual component of a bimodal visual-tactile stimulus, but an almost non-existent slope for the same stimuli when attending toward this type of stimulus. An increased amplitude reflects an increase in synchronous cortical excitability (and vice versa), suggesting that while attending toward the visual component of a bimodal visual-tactile stimulus, there was no relationship with trait anxiety; however, when attending away, there was a decrease in cortical excitability of generators of the P2 visual ERP as trait anxiety increased. This study replicated Adams et al. (2017)'s findings that task relevance affected P2 amplitude, but not those of P1 and N1. The effect of attention on P2 amplitude by Adams et al. in 2017 was not replicated by their later work (2019; 2020), which is why a hypothesis was not formed around this ERP. In accordance with Adams et al.'s (2017) findings, attention (i.e., task relevance) significantly contributed to the goodness of fit of half of the P2's linear mixed analyses and not those of P1 and N1. Though neither the main effect of attention nor the interaction or trait anxiety and attention

reached significance for P2 amplitude, this is, again, likely due to the limited sample size for two predictors in a linear model.

Recent work by Xiu and colleagues (2022) showed a significant relationship between neuroticism (which has been argued to be closely linked with trait anxiety) and the visual P2 in a 2-back working memory task. As in this study, they measured the P2 relative to the N1 negativity, otherwise known as the N1-P2 complex. They found that P2 amplitude in the target condition was higher in the high neuroticism group compared to low neuroticism at Fz, Cz, and Pz electrodes (Xiu et al., 2022). They also found slower P2 latencies in the nontarget condition in high compared to low neurotic subjects. Similar to the effects seen in this study, Xiu et al. (2022) were unable to find a relationship between visual N1/N100 properties and neuroticism. Unlike the work of Xiu et al. (2022), this study did not find a facilitation of P2 amplitude in response to a target (or "attended toward" stimulus); rather, there was a negative relationship between P2 amplitude and trait anxiety when instructed to attend away from the visual component of a bimodal stimulus that was not present when instructed to attend towards it. It is possible that a decrease in P2 amplitude is correlated with increased attentiveness toward a visual stimulus (Crowley & Colrain, 2004). If so, the decrease in P2 amplitude with higher trait anxiety when instructed to attend away from the visual component of a bimodal stimulus in the present study may indicate an increase in attentiveness toward the visual distractor when simultaneously presented with a tactile stimulus. Importantly, Xiu et al. (2022) found no relationship between behavioural performance and neuroticism, similar to the findings of the present study. With this recent supporting evidence of a relationship between neuroticism and the N1-P2 complex, this further supports our findings that there is a reduction in the ability to inhibit distractors from one's attention with higher trait anxiety (or neuroticism) as indexed by P2 amplitude without a distractor cost for behaviour incurred.

Trait anxiety and attention influence visual P3 latency

The P3 is a large, broad potential that occurs in response to all sensory stimuli of all types (i.e., visual, auditory, somatosensory) (Dreo, Attia, Pirtošek, & Repovš, 2017). In the present study, the visual P3 was analyzed in the context of trait anxiety and attention while attending toward and away from unimodal visual stimuli, as well as for the visual component of bimodal visual-tactile stimuli. The P3 had not yet been explored by Adams et al. (2017; 2019; 2020) using this task; thus, there is no direct comparison of this ERP to past work, unlike the others. While the P3 is customarily examined in the context of stimulus predictability and categorization (i.e., in the oddball paradigm), it is also modulated by motivational relevance, similar to the attentional manipulation shown in this study (see review by Nieuwenhuis et al., 2005). In the current study, this was found with a strong effect of attention on P3 amplitude in response to bimodal visual-tactile stimuli; however, this effect was not seen in response to unimodal visual stimuli.

The P3, which typically occurs in response to task-relevant stimuli, is thought to be linked to the LC-NE system. Nieuwenhuis et al. (2005) reviewed this concept and proposed that P3 reflects the phasic enhancement of gain as a result of enhanced LC-NE activity. The thalamus and hippocampus are thought to be involved in P3 generation (Herrmann & Knight, 2001)–both structures are recipients of projections from the LC, as well as the neocortex (including the PFC) and many other forebrain areas (Bouret & Sara, 2005). Bouret & Sara (2005) stipulate that another important criterion to induce a response in LC neurons is uncertainty, which this study's experimental task fulfilled with the randomized stimuli. This task also presented a sense of uncertainty to the participants because in contrast to the training session with visual feedback, there was a lack of feedback when responding in the behavioural task that may have contributed to the overall uncertainty while performing the task.

The amplitude of the P3 ERP is associated with the task relevance and probability of the stimulus, while its latency is associated with stimulus evaluation time (Donchin & Coles, 1988). Thus, the results suggest that trait anxiety shows a positive relationship with stimulus evaluation time when attending toward a task-relevant unimodal visual stimulus; however, when exposed to a task irrelevant unimodal visual stimulus, this becomes a negative relationship. This may relate to heightened anticipatory top-down activity in relation to the visual stimulus. For example, when high trait anxious individuals are preparing to respond to a unimodal visual stimulus as required, there may be greater gain in LC-NE activity and higher cortical influences during sensory processing. However, when instructed to attend to a crossmodal stimulus, these resources may be recruited for the opposite modality, reflecting a slowness in processing of the unimodal visual stimulus when presented as a distractor. Corbetta and Shulman (2002) described that a "salience" map, maintained by the dorsal frontoparietal system, combines afferent information with higher cortical influences during visual search. It is possible that individuals with lower trait anxiety used this salience map more effectively, with relevant visual information being processed faster than when irrelevant. In comparison, those with high trait anxiety showed the reverse, taking shorter stimulus evaluation time to process irrelevant visual information than less anxious individuals but longer to process relevant visual information. This is yet another indication that stimulus relevance plays a role in task-related processing relative to trait anxiety.

Trait anxiety & timing of ERPs relative to stimulus onset: observed sensory modality-dependent patterns

Early visual ERPs such as the P1, or in the case of tactile ERPs, P50 and N70, reflect "exogenous" processes related to physical properties of the stimulus rather than cognitive processes (Rugg & Coles, 1995). The N70, an early tactile ERP, showed a strongly or moderate relationship with trait anxiety, whether the effects were significant or not; however, this effect was only observed in late visual ERPs. The tactile P100 and N140 ERPs are considered as mid-latency relative to stimulus onset and are thought

to reflect cognitive or "endogenous" processes (Desmedt & Tomberg, 1989; Schubert et al., 2008). Somatosensory and visual sensory inhibition and gating are mechanistically different (see review by Knight et al., 1999), with tactile stimuli being gated out much earlier than visual stimuli. In other words, endogenous, or higher-order influences (i.e., manipulations in attention) impact ERP markers at earlier stages of tactile than visual processing (Adams et al., 2017). The results in this study follow this trend, indicating a relationship between trait anxiety and the amplitude or latency of early-to-mid-latency tactile components (i.e., N70) and mid-to-late latency visual components (i.e., P2, P3). Importantly, the effect of trait anxiety seems to be more related to ERPs shown to be susceptible to attentional influences and endogenous sensory processing (i.e., N70, P2, P3) in this specific task rather than exogenous processing (i.e., P50, P1, N1).

Attentional contributions to linear mixed models

Unexpectedly, the addition of attention as a fixed factor did not significantly improve the goodness of fit of the N70 linear mixed analyses, like those of P50, P100, and N140. This finding contrasts to those of Adams et al. (2017, 2019, 2020), that found that N70 amplitude was significantly larger when attending toward tactile stimuli than when attending away. This effect was not found after inhibition of the prefrontal cortex with cTBS (Adams et al., 2019), suggesting that there is a prefrontal contribution to the facilitation of relevant tactile information in this task, as indicated by N70 amplitude. Though attention did not significantly contribute to tactile ERP properties, this was significantly more so for the visual modality, where the later P2 and P3 potentials were modulated by attention. Overall, it has been repeatedly shown that attention modulates somatosensory processing and ERPs earlier than for visual because these two modalities are thought to be driven by different modulatory processes (see review by Knight et al., 1999).

4.4 Trait Anxiety Shows No Relationship to Behavioural Distractor Cost

In accordance with ACT's notion that anxiety impacts performance effectiveness less so than processing efficiency, behavioural results in this study showed no cost to accuracy when exposed to a crossmodal distractor compared to without one. Subjects were instructed to prioritize accuracy and were given ample time (3 s) between stimuli to produce a response. The sensorimotor task may not have been demanding enough to show a pronounced effect of anxiety on performance. In this study, there was emphasis put on the subjects' accuracy, not reaction time. Studies putting time-pressure on participants would be more likely to induce an effect of state anxiety, which was not the focus of the current thesis. Three seconds was ample time for participants to respond and allowed them to focus on accuracy.

The behavioural results were qualitatively similar to Adams et al. (2020), where the presence of a visual distractor with a tactile stimulus trended towards a larger distractor cost than a tactile distractor with a visual stimulus. In this study, the addition of sensory modality significantly contributed to the LMM. Although it did not reach significance, the main effect of sensory modality showed a moderate effect, indicating that across all individuals, the presence of simultaneous visual distractors moderately affected the distractor cost compared to simultaneous tactile ones. There was no interaction between trait anxiety and sensory modality of the simultaneous distractor. Thus, trait anxiety did not impact distractor cost of visual distractors differently than for tactile ones.

If the goal would have been to evoke a larger distractor cost, the task could have been modified slightly. More detailed hypotheses in ACT state that more specific ways that trait anxiety impairs efficiency, and often performance effectiveness, are in tasks involving the shifting and inhibition functions, especially when exposed to "threat-related" distractors (Eysenck et al., 2007). More frequent attentional switching between modalities within blocks may have magnified this effect. Another way would be to introduce threat as a factor, with threatening visual (i.e., fearful vs. neutral faces that vary in size instead of vertical bars) or tactile (i.e., shock vs. vibration) stimuli.

4.5 Limitations

There are a few limitations to this study that may have resulted in results that approached but did not quite reach significance despite demonstrating medium-to-large effect sizes. Particularly relevant was the large effect of trait anxiety on N70 amplitudes in response to bimodal stimuli that approached significance. First, the bandpass of 0.1-30 Hz may have been too stringent; in particular, collection of the data with a low-pass filter of 30 Hz. This may have caused a lack of sensitivity in the acquisition of ERP amplitudes due to a flattening of the peaks. Data collection with a more liberal low-pass filter (e.g., 100 Hz) with later application of still a more liberal low-pass filter, if needed, (e.g., 50 Hz) is recommended in similar studies to reduce potential distortions of the EEG waveforms. Another factor that may have contributed to the broadening of ERP peaks was the lack of removal of "incorrect" trials from the averaged ERPs for each individual. Incorrect trials (false positive or false negative responses) were, however, removed and identified later during behavioural analysis. Notably, due to the somewhat simple nature of the task, there were relatively low percentages of errors across all participants (10 to 15 errors out of 360 trials per stimulus type), making the differences in ERP amplitudes and latencies with incorrect response trials removed quite marginal. Despite these small differences, they may have been enough to dull the effects observed. Also, although the sample size reached the overall goal set out by the *a priori* power calculation, three participants had to be removed from analysis. Furthermore, there were several missing data points since in some cases, a given ERP was not observed for some participants in certain conditions (see degrees of freedom in LMM results). With this in consideration, the addition of several more individuals may have raised the statistical power sufficiently to reach significance in some borderline measures.

Another limitation of this study was the inability to ensure that participants were effectively attending toward or away from stimuli, which may have had the potential to impact both the ERP and behavioural data. While they were instructed to keep their eyes fixated in the centre of the visual stimulus

presentation screen, there was no quantitative or qualitative assessment of whether their gaze was properly located trial by trial. Eye tracking could be implemented in similar studies in the future to address this potential confound with visual attention. It is, however, more difficult to ensure the subjective control of attention toward tactile stimuli. This could be addressed with thought probes randomized periodically throughout experimental blocks to assess whether subjects were diverting attention as instructed.

Finally, it should be acknowledged that the validity while using self-report is not fool proof, particularly with personality assessments such as the STAI. Use of self-report introduces possible biases, with the most applicable for this study being social desirability bias (Althubaiti, 2016). This form of bias is more likely to occur at times when anonymity is not guaranteed (Althubaiti, 2016). While confidentiality was guaranteed and maintained during and after experimental sessions, it was out of the scope of the study to completely maintain anonymity between the experimenter and the subjects. For this reason, the scores on the STAI-Y2 form that assessed trait anxiety may not have been fully accurate depictions of subjects' true thoughts and feelings despite instructing them to respond as honestly and accurately as possible. The measure of trait anxiety was a critical component of this thesis as the dependent variable all analyses performed. If possible, a strictly anonymous scoring process is recommended in future work to further minimize self-report bias. More rigorous testing methods, including questionnaires with validity scales and strong convergent validity with other scales, are also recommended for more robust methodology in trait anxiety research.

4.6 Conclusion & Future Directions

Trait anxiety in healthy adult populations has been studied at length to determine how individual differences may affect executive functions underlying everyday cognition. While a deficit in the efficiency of inhibition of irrelevant information has largely been documented in the visual modality with

traditional cognitive tasks, this had rarely been explored in a bimodal context in conjunction with neurophysiological methods. The current study's findings demonstrated 1) alterations in electrophysiological correlates of neural "processing efficiency", as demonstrated in early tactile and late visual ERPs as biomarkers of attention and sensory processing (i.e., affecting amplitude and latency based on attention), and 2) trait anxiety did not impact "performance effectiveness," as demonstrated by a lack of differences in distractor cost to behavioural accuracy in the sensorimotor task. This study demonstrates the first evidence that individual differences in anxiety impact early cortical markers of tactile sensory processing (N70 latency). Furthermore, it demonstrated trait anxiety-attentional interactions in electrophysiological markers of crossmodal visual-tactile stimulus processing (P2 amplitude) and visual processing (P3 latency). The current study's findings contribute to a greater understanding of whether there is an imbalance between top-down and bottom-up attentional processing in relative trait anxiety.

Taken together, this study reinforces the notion that although there may not be clear behavioural implications of trait anxiety on accuracy in simple attentional task in a controlled experimental setting, there are underlying dynamic sensory and cognitive neuroelectric differences as a result of this trait. Now that these underlying neural differences are established, next steps would be to assess the relationship between trait anxiety, attention, and markers of sensory processing in experimental tasks with higher sensory load as well as in more ecologically valid environments, as in real-world situations, there are more than two competing sensory modalities at a given moment. The use of multiple methods in conjunction with EEG, such as pupillometry, would be beneficial can be used to assess potential LC-NE influences related to trait anxiety during the task.

This research is important from a basic science and clinical perspective to better understand the functional implications of dispositional anxiety on sensorimotor processes involving manipulations in attention in healthy individuals. Moving forward, studies examining the effect of trait anxiety on the dynamic control of attention and sensory reweighting (i.e., involving event-related spectral perturbations),

different behavioural measures (i.e., both reaction time and accuracy), and sex-related differences should also be further investigated. Studies incorporating crossmodal stimuli can continue providing an understanding of the basis as to how trait anxiety may affect attention and sensory processing in everyday cognition. Furthermore, there are numerous clinical links to trait anxiety (often used interchangeably with neuroticism) in assessing predisposition to developing psychiatric disorders, managing subclinical symptoms, or in understanding comorbidities with neurodevelopmental and psychological conditions. These findings contribute to progress in understanding the impact of individual differences in anxiety on sensorimotor function, which may contribute to clinical knowledge, an understanding of how individual differences in anxiety can impact activities of daily living (i.e., such as driving, cooking, and navigating through one's environment), and bridge current gaps in understanding cognitive and attentional biases across the spectrum of anxiety.

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Appendix: Within-Subjects Results Plots

To represent within-subject values for attention (Fig. i, ii, iv) and distractor cost modality (Fig. v), Pearson Product Moment Correlations were conducted on the differences between conditions relative to trait anxiety (STAI-Y2 score). Scatterplots with *R* coefficients and *p*-values are shown below.

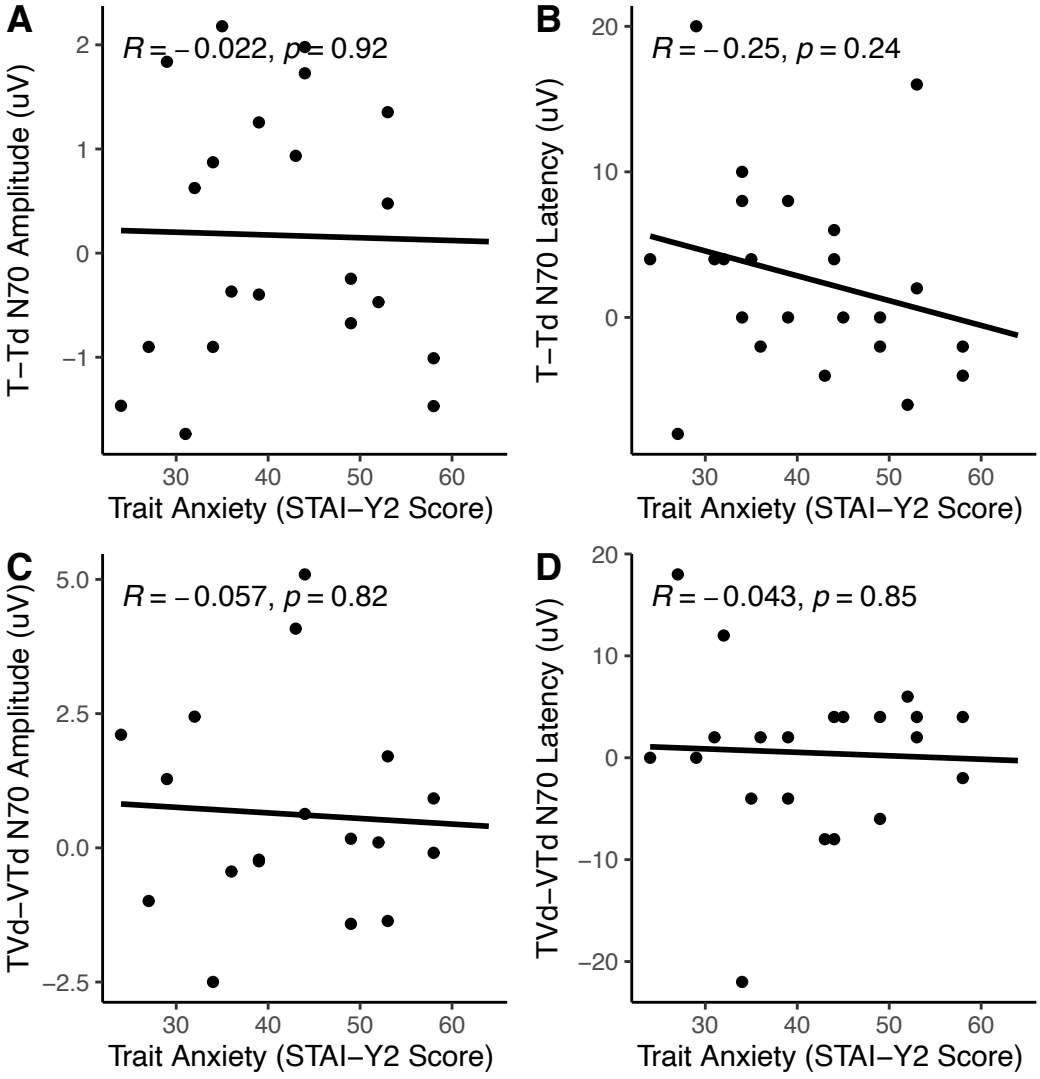

Figure i. Within-subjects version of Figure 5 depicting the effect of trait anxiety (STAI-Y2 score) and within-subject differences between attentional condition (toward-away) on tactile N70 peak amplitudes and latencies. A. N70 amplitudes in response to unimodal tactile stimuli (T-Td). B. N70 latencies in response to unimodal tactile stimuli (T-Td). C. N70 amplitudes in response to bimodal visual-tactile stimuli (TVd-VTd). D. N70 latencies in response to bimodal visual-tactile stimuli (TVd-VTd). No significant correlations were observed.

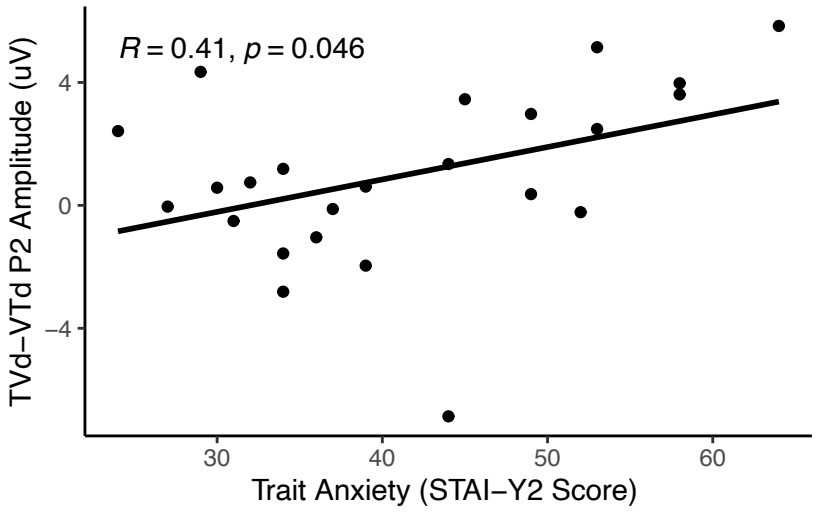

Figure ii. Within-subjects plot of Figure 7. A weak positive correlation between trait anxiety and difference in attentional conditions (toward-away) of visual P2 ERP amplitudes in response to bimodal stimuli was observed ($p < 0.05$).

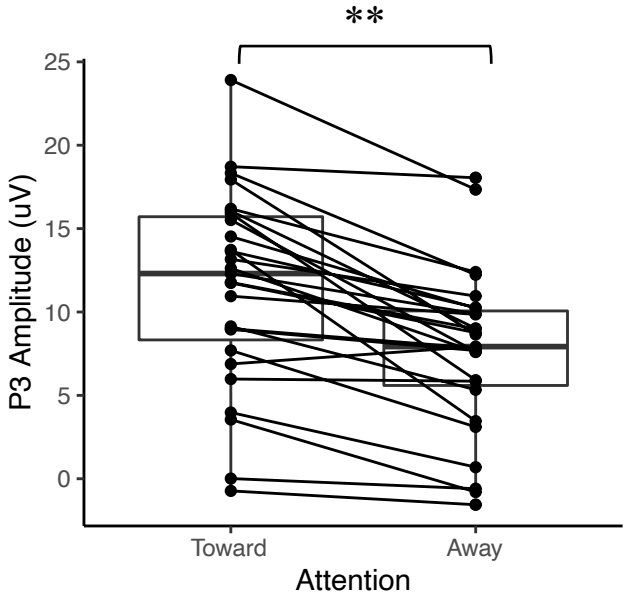

Figure iii. Within-subjects plot of Figure 8. A significant effect of attention on visual P3 ERP amplitudes in response to bimodal visual-tactile stimuli was observed. Each connection line between two points represents the differences in P3 amplitude as a function of attention (toward vs. away) in one participant. When diverting attention toward the visual component of the bimodal stimulus, P3 amplitudes were significantly larger than when attending away from the visual component (toward tactile). $^{**}p < 0.05$

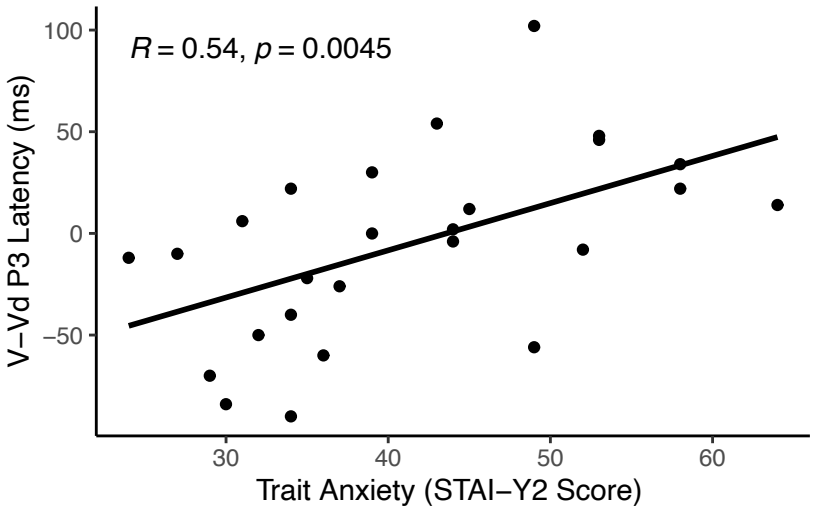

Figure iv. Within-subjects plot of Figure 9. A moderate positive correlation between trait anxiety and difference in attentional conditions (toward-away) of visual P3 ERP latencies in response to unimodal visual stimuli was observed ($p < 0.05$).

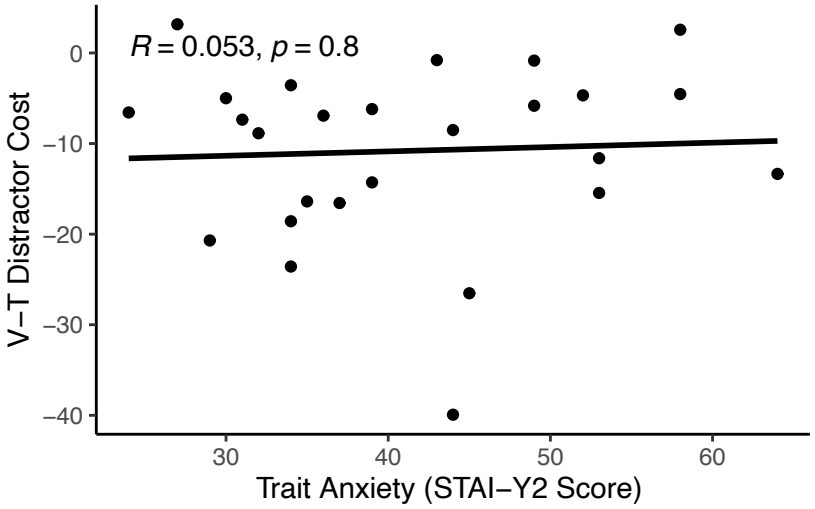

Figure v. Within-subjects plot of Figure 10. No correlation between trait anxiety and distractor cost relative to the difference between sensory modality of the stimuli (visual distractor condition-tactile distractor condition) was observed.