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Savanah Calton
Brigham Young University

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The Behavioral and Neurophysiologic Relationships Between Sensory Processing and Autistic Traits in Emerging Adults

Savanah Calton

A thesis submitted to the faculty of Brigham Young University in partial fulfillment of the requirements for the degree of Master of Science

Garrett Cardon, Chair
Shawn Nissen
Christian Sabey

Department of Communication Disorders
Brigham Young University

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Savanah Calton
Department of Communication Disorders, BYU
Master of Science

The majority of individuals diagnosed with Autism Spectrum Disorder (ASD) experience sensory processing difficulties that are also associated with greater presence of autistic traits, psychiatric difficulty, and intolerance of uncertainty (IU). These relationships are also expressed in the neurotypical (NT) population, termed the Broader Autism Phenotype (BAP), and present with impacts to daily functioning/well-being just as prominently. However, little is known concerning the neurophysiologic nature of these behavioral relationships, especially in young adults. Thus, the purpose of the current study was to examine the behavioral and neurophysiologic nature of the relationships between sensory processing, autistic traits, and related behavioral functions in NT young adults. To accomplish this, approximately 1200 NT university students aged 17-26 years old completed a compilation of behavioral questionnaires addressing sensory processing difficulties, autistic trait expression, psychiatric difficulties, and IU. A subset of this sample, \( n = 55 \) participated in a resting-state fMRI to evaluate atypical connectivity between sensory-related and supramodal brain regions. Partial correlations of behavioral measure total and subtest scores reveal that sensory processing, autistic traits, IU, and empathizing are all significantly correlated with each other. Between-groups comparisons of college major groups show that these behavioral relationships are heightened in particular fields of study (e.g., physical and mathematical sciences). Cluster analysis demonstrates that a subset of participants with first-degree relatives possessing an ASD diagnosis exhibit less favorable scores on all measures. Finally, neurophysiologic results portray that atypical functional connectivity between sensory-related brain regions (i.e., bilateral pre/postcentral gyri) and supramodal brain areas (i.e., bilateral supramarginal gyri, sensorimotor/cerebellar network, and salience network) is connected with increased total scores of autistic traits, sensory processing, and IU. These results are novel—as they show brain networks related to autistic trait expression in the NT population that may help with identifying neural contributors to ASD, thus, improving objective diagnostics and physiologic supports/interventions. In addition, these findings increase awareness of the daily functional, and challenging, impacts of sensory processing difficulties and autistic traits on all individuals, independent of diagnostic status. Therefore, accommodations/services could be improved for young adults in clinical, educational, and personal settings to improve overall quality of life.

Keywords: autism, anxiety, sensory experience, sensory integration, prediction, neurosciences
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DESCRIPTION OF THESIS STRUCTURE AND CONTENT

This thesis, *The Behavioral and Neurophysiologic Relationships Between Sensory Processing and Autistic Traits in Emerging Adults*, is written in a hybrid format. The hybrid format combines thesis formatting with journal-ready publication methods. The preliminary pages of the thesis reflect requirements for submission to the university. However, the thesis itself is presented as a journal article and conforms to style requirements for submitting research reports to scientific journals. Identity-first language (e.g., “autistic participants”) is used throughout the paper due to its growing favor over person-first language in autism communities and published data supporting its use (Kenny et al., 2016). However, we also acknowledge and respect many people’s preference for person-first language. The annotated bibliography is included in Appendix A. Appendix B contains the consent/Institutional Review Board approval letter. Appendix C includes supplementary data.
Introduction

Autism Spectrum Disorder (ASD) is traditionally characterized by difficulties with social communication and restricted and repetitive patterns of behaviors. Recently, hyper- and/or hypo-reactivity to sensory input was added as a core feature of ASD (American Psychiatric Association [APA], 2013). Several studies have shown that each of these diagnostic criteria can be seen to some extent in the neurotypical (NT) population (De Groot & Van Strien, 2017; Landry & Chouinard, 2016; Robertson & Simmons, 2012). Whether they are experienced by people with or without an ASD diagnosis, the aforementioned characteristics can be challenging for children as well as adults (Crane et al., 2009). In contrast to the many studies concerning sensory characteristics in infants and children, there is limited high-quality research available concerning autistic emerging adults. Additionally, the prevalence of autism continues to rise—having increased from one in 59 children in 2014 to one in 54 in 2016 (Baio et al., 2018; Centers for Disease Control and Prevention, 2019). This upsurge means there are and will be ever more autistic adults, which concomitantly increases the need for related research (Gadke et al., 2016; Wigham et al., 2019).

Due to the lack of available research and recent focus, at least one aspect of autism that is poorly understood in emerging adults is sensory processing. While previous investigations indicate that there is a significant correlation between the severity of atypical sensory processing and presence of autistic traits (Robertson & Simmons, 2012), the neurobiological underpinnings of this association are not yet well understood. The current study aims to examine the behavioral and neurophysiologic relationships between sensory processing, autistic traits, and related behavioral functions across NT young adults. Discovery of neuronal networks involved in atypical sensory processing and autistic traits could provide increased understanding of ASD etiology, assessment methods, and service goals, leading to an overall improved quality of life for those who express these characteristics, whether they have a diagnosis, or not.
**Autism Spectrum Disorder**

In addition to the core features of ASD, autistic individuals can present with difficulties in a variety of other domains: language, cognitive skills, behavior, theory of mind, and emotion regulation (Centers for Disease Control and Prevention, 2019). However, the degree to which each of these facets of autism may be present in an individual varies greatly. The term “spectrum” was added to the diagnostic title due to this heterogeneity (APA, 2013). Likewise, there are many who express autistic traits who do not have or meet full criteria for an ASD diagnosis, which supports the idea that autistic traits are distributed along a spectrum that extends into the NT population (termed the *Broader Autism Phenotype* [BAP]; Landry & Chouinard, 2016). While those who receive an official diagnosis qualify for support services, those who are not considered to be on the spectrum, but still express autistic traits, do not. Such circumstances can create difficulties for undiagnosed individuals, as they are often left without clinical support and a known title/category for their characteristics (Volkmar et al., 2004).

The process of ASD diagnosis is complex (e.g., male-centric diagnostic procedures and scoring, limited access to high-quality diagnostic assessments for adults, no physiologic measures to date, unclear diagnostic borders due to the BAP; Corbett et al., 2021; McKinney et al., 2018; Volkmar et al., 2004; Wigham et al., 2019). Because of these intricacies and the limited research on autistic adults, the prevalence of ASD diagnosis in adults may be greatly underestimated—leaving these individuals potentially overlooked in the years between childhood and adulthood (McKinney et al., 2018). Diagnosis can occur as early as 18 months but is considered highly reliable by age two (Centers for Disease Control and Prevention, 2019; Hyman et al., 2020; Lord et al., 2006). Though this is true, many children do not receive a diagnosis until they are older—potentially in adolescent or adult years, which affects the timing of and access to beneficial resources/services. This pattern may be especially pronounced in females (Corbett et al., 2021). Later diagnosis may be due to a
number of reasons, including variation in symptoms/characteristics and borderline severity which greatly effect diagnostic methodology (Daniels & Mandell, 2014; Dietz et al., 2020).

In all, autism diagnosis is a difficult and time-consuming process, requiring expertise by a highly trained group of professionals and clinicians. Because the diagnostic methods of ASD are largely based on (often isolated) observations and due to the heterogeneity of autism, signs of the disorder may be overlooked. In such cases, undiagnosed individuals must self-manage the effects of the difficulties they experience. Unfortunately, engaging in this type of self-management, without the knowledge of a diagnosis and associated supports, can contribute to the development of anxiety and depression (Corbett et al., 2021). In addition, the training required to become a qualified diagnostician is extensive. Trends surrounding autism diagnosis, like those mentioned above, could lead to diagnostic and clinical landscapes that are eventually untenable. A physiologic measure that could aid in diagnosis would help such a challenge. Additionally, such a measure may be able to provide information about sub-types of the autism diagnosis, which could lead to improvements in support strategies. Thus, as autism prevalence increases, the clinical and scientific communities are needed to help improve diagnostic procedures and provide services for autistic individuals.

Efforts related to the above are underway. For instance, the fractional nature of the core characteristics of ASD (i.e., social communication deficits and restricted and repetitive patterns of behaviors) has been frequently examined. Investigators question whether and/or how much of each of these characteristics have a common underlying cause (e.g., genetics, environmental) or if they are entirely separate. Currently, family and twin studies have suggested that these core characteristics are separate factors of the autism phenotype that have both individual and shared genetic and environmental determinants. The early development of several other aspects of communication including verbal output, articulation patterns, semantic-pragmatic skills, difficulties with inhibition, and social understanding are all also identified to have predictive power of a later
ASD diagnosis (Maxwell et al., 2013; Steer et al., 2010). While these studies have demonstrated potential underlying genetic components, genetic studies have yielded only the possibility of identifying biomarkers capable of displaying the ASD phenotype (Geschwind, 2011). Furthermore, while many other studies suggest that the core characteristics of autism may not have a common underlying genetic factor, the fact remains that fundamental autistic traits regularly occur together in millions of people. Thus, work in the area of determining the physiologic underpinnings of autism is still greatly needed.

Sensory processing is one area that has been understudied in terms of its role as the common underlying factor in both social communication/language and restricted and repetitive behaviors. That is, in the DSM-5, atypical sensory processing falls under the larger category of restricted and repetitive behaviors and has been shown to be connected to the same at various levels (Bishop et al., 2013; Boyd et al., 2010; Lindstone et al., 2014). Additionally, many theorize and have shown that sensory processing is highly correlated with aspects of language and social communication (Bigler et al., 2007; Foss-Feig et al., 2017; Gilga et al., 2014; Hannant et al., 2016; Hilton et al., 2007; Lincoln et al., 1995; Matsushima & Kato, 2013; Philpott-Robinson et al., 2016; Reynolds et al., 2011; Tavano et al., 2007; Thye et al., 2017; Watson et al., 2011). Thus, it is reasonable to argue that the shared factor between the core symptoms of ASD could be atypical sensory processing.

In addition to sensory processing, an ASD diagnosis presents an array of subsequent challenges for both diagnosed individuals and their families. The possibility of co-occurring conditions, developmental delays, health service needs, financial and time burdens, an unpredictable future, and new family dynamics can all increase as a result of this diagnosis (Kogan et al., 2018). Additionally, though a variety of therapies and medications are available to support autistic individuals, interventions, overall, are still under great scrutiny. Given prevalence increases, barriers to diagnosis, and added difficulties to the lives of affected individuals and families, the need for
further research is clear. Unfortunately, while the reported impact of ASD on young adults is significant, research on this age group is limited (McKinney et al., 2018).

In this search for a link between the core elements of autism and the related challenges discussed above, the BAP perspective may prove to be highly valuable (Landry & Chouinard, 2016). While ASD is an established and valid diagnosis, in reality, autistic traits seem to be variably expressed by many in the general population along a spectrum without bounds. Thus, studying people who are not diagnosed with ASD, but express varying levels of autistic traits and/or atypical sensory processing, may provide a useful window into important aspects of autism. Furthermore, those who express autistic traits, regardless of diagnosis, may also benefit from supports for which they currently do not qualify. Studying emerging adults using the BAP model will allow the opportunity to observe these phenomena for both the benefit of diagnosed individuals and those beyond diagnostic borders that are also in need of accommodations. This dimensional approach is also consistent with the National Institute of Mental Health’s Research Domain Criteria (RDoC; U.S. Department of Health and Human Services, 2021).

**Autism and Co-Occurring Difficulties in Emerging Adults**

The aforementioned prevalence statistics focus primarily on autistic children, despite the fact that autism is a part of a person’s identity across the lifespan. In some regards, the results of an autism diagnosis on young adults can be just as, if not more impactful, than they are on children (Boulter et al., 2014; Dunn et al., 2016; Thye et al., 2017). For instance, studies show that autistic teens and adults present with fewer life-engaging opportunities than their typically developing peers—e.g., these individuals demonstrate higher rates of unemployment/underemployment and low participation in education beyond high school (Centers for Disease Control and Prevention, 2019; Levy & Perry, 2011; Roux et al., 2013). Also, only 35% of autistic youth attend college compared to 41% of NT young adults (Houle & Warner, 2017; McKinney et al., 2018). The transition to
attending college requires encounters with novel challenges for those who attend, including living independently, identifying personal beliefs, forming new relationships, and pursuing careers, all while balancing academic responsibilities (Gadke et al., 2016). The weight of these changes, for both autistic individuals and NT peers, positions this population (i.e., ages 17-25) to experience the highest rates of psychiatric difficulty, including anxiety and depression, compared to those in other life periods (Gadke et al., 2016). Due to these difficulties, many autistic adults continue to live with family members far beyond emerging adulthood and have limited opportunities for community and/or social activities—e.g., approximately 40% of autistic individuals spend little to no time in social groups (Dudley et al., 2018). In addition, a correlate of comorbid psychiatric illness in autistic youth is high rates of death by suicide. While suicide was the second leading cause of death for individuals 10-24-years-old in 2019—a highly concerning figure—this risk is three times higher in autistic individuals (Centers for Disease Control and Prevention, 2019; Kõlves et al., 2021).

The ASD “cliff” refers to the reality that the abundance of services that are available to autistic students during high school, including therapeutic services and personal assistance, are no longer federally required to be offered after the last day of high school (Roux, 2015). Additionally, many of the services available to adults with disabilities require a diagnosis of intellectual disability for qualification. Most often, this does not apply to autistic adults, leaving them excluded from services that could be crucial to their success in adulthood, such as those that facilitate finding a job, continuing education, and living independently (Roux, 2015). This predicament may further contribute to the prevalence of comorbid psychiatric illness in this population.

It is highly likely that atypical sensory processing contributes to many of the above challenges (Dunn et al., 2016). For example, numerous studies have found significant correlations between atypical sensory processing and high levels of anxiety. The literature is abundant concerning this relationship in infants, toddlers, and children—providing evidence that atypical
sensory processing predicts and exacerbates later emerging anxieties often related to sensory-specific phobias (Boulter et al., 2014; Dwyer et al., 2020; Green et al., 2012; Lau et al., 2020; South & Rodgers, 2017; Wigham et al., 2015). Research that follows this correlation into adolescence and adulthood for autistic individuals is still emerging, but has yielded trajectories paralleling the pediatric literature (e.g., Uljarević et al., 2016). For instance, a study of autistic emerging adults reported that sensory over-responsivity significantly correlated with aggressive behaviors and that anxiety was a mediating variable between these two factors (Syu et al., 2020). In addition, more than 64% of the autistic participants in this study scored on or above the cut-off for generalized anxiety disorder. A similar study found that autistic adults self-reported a lower quality of life and social relationships, compared to NT peers, which was significantly associated with more anxiety and greater sensation-sensitivity in study participants. These results demonstrate the impact of not only some autistic traits but atypical sensory processing and associated comorbid psychiatric illness on overall quality of life (Lin & Huang, 2019).

The literature currently explains that the relationship between sensory processing and anxiety is mediated by intolerance of uncertainty (IU)—i.e., “the tendency to react negatively on an emotional, cognitive, and behavioral level to uncertain situations and events” (Boulter et al., 2014, p. 1392; South & Rogers, 2017; Wigham et al., 2015). Even without an autism diagnosis, IU is labeled as a risk factor for the development of clinically significant levels of anxiety (Carleton, 2012). Individuals who have difficulty with IU can find ambiguity to be stressful and highly negative. Therefore, IU is often seen as a threat to the success and positive view of various life situations. Intense reactions to uncertainty can cause significant responses of somatic stress that often result in the development of anxiety (Boulter et al., 2014). As novel stimuli and challenges continually unfold in individuals’ lives, anxiety is maintained and, perhaps, increased, due to the internal belief that new experiences will be unpleasant (Wigham et al., 2015). In fact, as they attempt to build
predictability into their lives, IU may be related to some of the traits commonly expressed in autistic individuals—i.e., insistence on sameness, rigidity, and difficulty with change and transition.

Given the connection between IU and autistic traits, it is important to investigate the impacts of uncertainty on autistic individuals and those who exhibit elevated degrees of autistic traits. For instance, Dwyer et al. (2020) identified that anxiety increased in children transitioning from preschool to school age—a time with heightened sensory input and exposure to an abundance of new stimuli, which may indicate that a new or an increased level of sensory input, without control, leads to more anxiety. This same pattern may also, and especially, be evident in individuals during emerging adulthood, as this is a highly transitional phase of life that involves many anxiety-provoking experiences. Furthermore, if autistic individuals have a greater likelihood of expressing comorbid psychiatric illness and experiencing IU, it is reasonable to believe that individuals without a diagnosis who present with increased autistic traits and atypical sensory processing might also have elevated levels of the same. If the effects of atypical sensory processing can be decreased through intervention, it could also potentially lead to the decrease of comorbid psychiatric disorders and associated effects and improve quality of life.

**Sensory Processing in Autism**

Upwards of 90% diagnosed with ASD are said to experience sensory difficulty (Ben-Sasson et al., 2009; Crane et al., 2009; Jassim et al., 2021). Atypical sensory processing is commonly limited to the inclusion of behaviors such as aversion to bright lights or loud sounds, pain response to certain textures of clothing, and/or significant difficulty with multiple simultaneous sensory inputs (i.e., “sensory overload;” Chistol et al., 2018; Dwyer et al., 2020; Hurley et al., 2007). This unpleasant relationship with sensory stimuli often results in more sensitive and emotional responses to sensory input and avoidance of sensory-rich environments (Crane et al., 2009; Mayer, 2016). Hypersensitivity, however, is not the only sensory difficulty among autistic persons. For instance,
both sensory hyposensitivity, which is characterized by below-normal levels of sensitivity to sensory input, and intense sensory seeking behaviors are also common in autistic individuals (Dunn, 2007). In these patterns of behavior, individuals “under-react” to sensory input or actively seek it due to the desire for stimulation, respectively. Autistic individuals that display hyposensitivity or sensory seeking behaviors may not react negatively to stimuli that others would typically find unpleasant or painful (e.g., pulling hair, deep pressure, or spinning). Instead, they may appear entirely unaware of any stimulation or intentionally pursue these sensory experiences (Robertson & Simmons, 2012).

All sensory modalities are, or can be, affected in autism. Within the same person, one or many modalities can be hyper- or hyposensitive while different patterns can be observed within other modalities. Equally, the manifestation of the same type of sensory abnormality can be equivalently severe but be expressed differently between individuals (Crane et al., 2009; Green et al., 2012; South & Rodgers, 2017). Some atypical sensory behaviors can be detected as early as six to 12-months of age and can be one of the earliest indicators of later autism diagnosis (Freeman, 1993; O’Neill & Jones, 1997).

Originally, atypical sensory processing was thought to diminish with age. However, recent studies have discovered that sensory difficulties can persist across the lifespan. For instance, a study of sensory processing in autistic adults demonstrated that 94.4% of autistic participants reported experiencing extreme levels of sensory difficulty in at least one quadrant of the Adult/Adolescent Sensory Profile (AASP; i.e., low registration, sensation seeking, sensory sensitivity, sensation avoiding; Crane et al., 2009; Tomchek & Dunn, 2007; see also Dwyer et al., 2020 & Mayer, 2016).

Atypical sensory processing has also been found to interfere with several other neurological functions including systemizing, empathizing, and autistic traits. Systemizing is defined as “the drive to analyze or construct rule-based systems, whether mechanical, abstract, or any other type” (Tavassoli et al., 2017, p. 73). Autistic individuals typically possess high levels of systemizing skills
which are used to predict and control the external world, or factors in it that are deterministic and finite (e.g., mathematics, technology). Using only this type of formulaic methodology, at times, leads to difficulties in predicting NT behavior, which requires additional abilities such as theory of mind, mentalizing, and empathy. Empathizing is defined as “attributing mental states to others” and “responding with affect to the other’s affective state” (Baron-Cohen et al., 2003; Baron-Cohen & Wheelwright, 2004, p. 164). Research has demonstrated that autistic individuals tend to have lower drives toward empathizing in many situations (Baron-Cohen et al., 2003; Tavassoli et al., 2017), though they may be adept at empathizing with others on the autism spectrum (Milton, 2012). In one study, results revealed that high levels of empathy were associated with fewer sensory symptoms and that greater levels of autistic traits were associated with more atypical sensory processing (Tavassoli et al., 2017). These findings suggest that atypical sensory processing can have an influence on an autistic individual’s ability to empathize, which may present obstacles to participating fully in social interactions. Furthermore, due to the above, NT individuals may have a harder time empathizing with those on the spectrum, which may lead to further social disconnection (Milton, 2012).

It is clear that sensory processing abnormalities can have negative impacts on several aspects of life; however, these sensory differences may also lead to strengths and distinct talents (e.g., attention to detail, high systemizing). In some cases, these sensory advantages may present individuals who experience them with employment, and other, positive opportunities that play to their strengths. Overall, the way in which external sensory stimuli is internalized impacts the cognition, behavior, and challenges/advantages experienced by any individual. Identifying a way, potentially neurophysiologic in nature, to modify the negative impacts of sensory differences may provide these individuals with the ability to engage in society and transitional phases of life more favorably.
**Broader Autism Phenotype**

To varying degrees, the correlations between autistic traits and atypical sensory processing expressed in ASD, and their impact on the transition to adulthood, are also demonstrated in the general population (Baren-Cohen et al., 2001). The well-established phenomenon of autistic traits more mildly or differently expressed by NT individuals is termed the Broader Autism Phenotype (BAP) and is consistent with the notion of an autism spectrum (Baron-Cohen et al., 2001; Constantino & Todd, 2003; Landry & Chouinard, 2016). Using the BAP to study NT individuals can inform the theoretical understanding of sensory processing and autistic traits in both ASD and NT development, as the relationships found in each group appear to be similar (Mayer, 2016). Early studies examining the existence of the BAP focused on first degree relatives of autistic individuals including parents, siblings, and twin studies (Constantino & Todd, 2003; Hallmayer et al., 2011; Landry & Chouinard, 2016; Narayan et al., 1990). These studies demonstrated that genetics played a prominent role in the etiology of ASD and accounted for the increased likelihood for an ASD diagnosis in siblings and the presence of shared behavioral traits (i.e., autistic-like traits, communication disorders) among family members (Gerdts & Bernier, 2011; Landry & Chouinard, 2016). One study found that as many as 10% of parents of autistic children and 20% of siblings expressed subclinical autistic traits (Landry & Chouinard, 2016). More recently, the BAP profile has been expanded and now addresses the milder presence of these traits in the general population as a whole, not just in families with autistic members (Landry & Chouinard, 2016; McKinney et al., 2018; Robertson & Simmons, 2012). Autistic individuals, in this case, can be viewed as one end of this spectrum of autistic traits that is applicable to the entire population.

Robertson and Simmons (2012) conducted a study concerning the relationship between sensory processing and autistic traits in NT adults. Results demonstrated that there is a highly significant and positive correlation between the number of autistic traits expressed and the level of
atypical sensory processing. Findings such as these were replicated by Mayer (2016), expressing that the “strength and pattern of this relationship is identical” (p. 316) between NT and autistic adults. In addition, these data support the reality of the BAP—that as the presence of autistic traits increases there is an increase in atypical sensory processing regardless of diagnostic standing.

A study by Dwyer et al. (2020) reasoned that using NT subjects supports the reality that there is a spectrum of sensory and autistic characteristics in both ASD and NT individuals. Likewise, employing groups of both types of subjects provides information for how to best support people all along the spectrum and demonstrates the amount of overlap of characteristics between groups. Therefore, it is justified to study the behavioral and neurobiological correlates of autistic traits, sensory processing, and other behavioral functions in the general population and utilize the findings to understand subclinical autistic traits. Identifying a way to decrease the negative impacts of sensory impairments could be beneficial to the daily lives of all, regardless of how or where they are identified on a spectrum of sensory and autistic traits. Given additional information about the relationship between sensory processing and autistic traits, accommodations could be made for those in the general population that need added assistance. Information could then be gleaned for how to support more intense cases of atypical sensory processing in those with an ASD diagnosis. Studying the BAP may also provide insight into the fundamental aspects of autism. Relevant to the current study, the BAP also provides a behavioral foundation upon which to study the neural connections demonstrated in these relationships.

**Neurophysiologic Underpinnings**

Many consider the behavioral patterns discussed above to arise from atypical brain connectivity (e.g., Belmonte et al., 2004; Cardon, 2018; Cardon et al., 2017; Hull et al., 2018; Kana et al., 2004; Minshew & Williams, 2007; O’Reilly et al., 2017). While this may be true, scientific consensus involving the brain regions and networks that contribute to autistic characteristics,
including sensory processing, is still limited. However, some patterns have begun to emerge, including atypical sensory processing’s association with aberrant connectivity within and between sensory regions of the cerebral cortex and supramodal brain regions (i.e., brain centers that integrate and modulate activity across sensory modalities).

The most commonly studied primary sensory regions of the cerebral cortex in autism research are the visual, auditory, and somatosensory systems. In a meta-analysis of functional magnetic resonance imaging (fMRI) studies that compared and contrasted brain areas between autistic and NT individuals, results demonstrated that autistic participants had increased activity within the primary sensory cortices (i.e., occipital, temporal, and parietal lobes) compared to NT participants (Jassim et al., 2021). More specifically, there was increased activity in visual processing cortices, particularly V2, a higher order visual processing area. Furthermore, the auditory cortices in autistic individuals revealed increased connectivity with the anterior cingulate cortex, frontal cortices, and angular gyrus—regions that contribute to the processing of pain and empathy, social function, executive function, and language. Lastly, the primary somatosensory cortex and supramarginal gyrus were more highly activated which was related to the hypo- and hyperreactivity to sensory input experienced by autistic participants. Because abnormal sensory processing was recently added as a diagnostic category of ASD to the DSM-5, there is high value in learning about the neurobiological substrates related to atypical sensory processing, and associated behavioral traits, in order to add insight regarding the origins of the same. Furthermore, there is potential to use these networks as biomarkers or phenotypes for earlier ASD diagnosis and targets for services (Jassim et al., 2021).

In attempting to discover the neurological correlates of sensory processing, it is also logical to study association sensory cortices, as well as supramodal brain areas. The fusiform face area (FFA) and other higher order visual processing regions, in particular, are important to study, given
previous work describing the associated difficulties and special abilities exhibited by autistic individuals within these areas (Robertson & Baron-Cohen, 2017). For example, the FFA functions as a face recognition area within the ventral stream of vision. Several studies have conducted fMRI using face perception tasks and discovered that there is decreased activity in this area for autistic individuals (Schultz, 2005; Schultz et al., 2003; Volkmar et al., 2004).

One supramodal area that is regularly implicated in ASD literature is the cerebellum (Courchesne & Allen, 1997; Kern, 2002; Molinari et al., 2009). While much of the extant literature assesses the cerebellum for its role in the motor system, evidence has also shown its role in sensation and higher order cognitive processing (Oldehinkel et al., 2019; Volkmar et al., 2004; Wang et al., 2018). One important role of the cerebellum is to synthesize inputs from all sensory systems, make predictions about what to expect in coming events, and prepare related systems to make appropriate responses to environmental inputs (Courchesne & Allen, 1997). Thus, if the cerebellar-cortical system is impaired in autistic individuals (i.e., hyper- and hypoactive connectivity; Ramos et al., 2019), prediction errors might occur on a more regular basis than in those who express fewer autistic traits (see Predictive Coding Hypothesis of Autism; Van Boxtel & Lu, 2013; Van de Cruys et al., 2014). Prediction mismatches (i.e., expecting one set of sensory inputs and experiencing another—like jumping into a swimming pool that was colder than expected) could adversely affect sensory processing, in that top-down and bottom-up contributions to such processing wouldn’t be combined adaptively. This could lead to overly literal processing patterns (Van de Cruys et al., 2014).

Additionally, those who frequently experience such mismatches might develop IU (Boulter et al., 2014; South & Rodgers, 2017; Wigham et al., 2015), and associated anxiety. That is, atypical prediction abilities might be associated with dislike, distrust, or aversion to unpredictable situations, as well as the tendency to build as much control, predictability, and sameness into life as possible (Tam et al., 2017). Finally, it is plausible to believe that impairment to cerebellar circuits might
interfere with motor function, social communication, language, and attention (D’Mello & Stoodley, 2015). Several of the behavioral traits expressed in autism may be physical expressions of this impaired circuit, such as insistence on sameness, sensory sensitivity, and theory of mind difficulties (Tam et al., 2017). All of the above may also be common in those without a diagnosis who express higher degrees of autistic traits.

Like the cerebellum, the amygdala is also commonly implicated in the study of sensory processing, autistic traits, and other related behaviors (esp. anxiety). This structure has been shown to lie at the nexus of sensory sensitivity and anxiety, and also social communication deficits and anxiety, in autism (Green et al., 2015; Tam et al., 2017). Typically, when the fear/emotional responses of the amygdala increase, the medial prefrontal cortex (mPFC) reacts by controlling or regulating the increased emotional response. In autistic persons, the connection between the mPFC and amygdala appears to be disrupted, leading to continually high levels of emotional response that supports the maladaptive development of anxiety (Jassim et al., 2021; South & Rodgers, 2017). Several models of emotion regulation have been developed for autistic individuals, but recent reports have demonstrated that the presence of atypical sensory processing, decreased emotion regulation, and rigidity of thought, coupled with high IU, result in these anxiety-related characteristics (Cardon et al., 2017; South & Rodgers, 2017).

While the aforementioned cortical networks and brain areas are hypo- or hyper-activated in autistic individuals, the current study hypothesizes to see similar networks and levels of reactivity in a sample of the general population of young adults due to the BAP. While intensity may be decreased, the relationships are predicted to be similar. Primary sensory cortices (i.e., medial occipital, superior temporal, and post-central gyri), association sensory cortices (i.e., lateral occipital, inferior temporal, and association auditory cortices), supramodal areas (i.e., cerebellum, amygdala, and large, distributed cortical networks), and the mPFC are predicted to be connected to
the behavioral traits expressed in ASD/the BAP including atypical sensory processing, autistic traits (e.g., systemizing, empathizing, social communication, IU, restricted and repetitive patterns of behavior), and psychiatric difficulty (i.e., anxiety, stress, depression).

**Aims and Hypotheses**

The current study aims to explore sensory processing and related behaviors along a more distributed spectrum of autistic traits. If significant associations between sensory processing and autistic traits exist in the NT population, the characteristics that make up autism could be viewed as a dimensional set of indicators across the general population rather than a synthesized categorical variable. Thus, the relationship, both behavioral and neurophysiologic, between sensory processing and autistic traits and related behavioral functions in young adults in the NT population will be explored. These findings have the potential to identify cerebral networks involved in atypical sensory processing and the presentation of autistic traits that could provide insight into the origins of ASD, improve diagnostic methods, and yield brain-based targets for services. Most importantly, these findings could eventually lead to an improved quality of life for those who express autistic characteristics to any degree that disrupts their daily functioning and desires intervention/accommodations/services to overcome their difficulties.

At first, we hypothesized that there would be a significant positive correlation among the level of sensory processing abnormalities, presence of autistic traits, and additional behavioral constructs. We also hypothesized that there would be a positive relationship between the functional connectivity of sensory-related brain regions and supramodal brain areas and behavioral measures.

**Method**

The current study was comprised of two phases. In Phase 1, participants were asked to fill out a set of questionnaires designed to examine several aspects of behavior—e.g., sensory processing, intolerance of uncertainty, social function, autistic traits. Subjects who were recruited
for, and accepted invitations to participate in, Phase 2 each underwent a resting-state fMRI (rs-fMRI) scan to evaluate functional network connectivity. Methods specific to these two study phases are discussed below.

**Phase 1: Behavioral Relationships Between Abnormal Sensory Processing, Autistic Traits, and Related Constructs in Neurotypical Young Adults**

**Participants**

We recruited approximately 1,200 (653 female) NT individuals ages 17-26 to complete a compilation of surveys and questionnaires that examined aspects of sensory processing, autistic traits, and other related behavioral traits (e.g., mental health). For the purposes of our study, any individual who didn’t self-report a diagnosis of autism was considered to be NT. Subjects were recruited via advertisements from local universities (i.e., fliers, email, highlighted in class lectures, clubs), word of mouth, the Brigham Young University psychology research pool (SONA), and social media platforms.

**Materials and Data Collection**

Each participant was asked to fill out the battery of surveys via an online platform (Qualtrics, Provo, UT). After we obtained consent and brief demographics, participants completed the Short Sensory Profile (SSP), Intolerance of Uncertainty Scale-Short Form (IUS-12), Glasgow Sensory Questionnaire (GSQ), Systemizing Quotient (SQ), Empathizing Quotient (EQ), Broad Autism Phenotype Questionnaire (BAPQ), Autism Quotient (AQ), and the Depression Anxiety Stress Scale 21 (DASS-21). The SSP (a truncated version of the Sensory Profile) assessed the presence of sensory symptoms in all modalities such as taste/smell, auditory filtering, and movement for each participant (Robertson & Simmons, 2012; Tomchek & Dunn, 2007). In addition, it separated respondent scores into one of three categories (i.e., typical performance, probable difference, definite difference) based upon how consistent with, or above average, their sensory difficulties...
were reported to be. Although the SSP was validated in children (Crasta et al., 2020; Glod et al., 2019; Simpson et al., 2019), studies of older children and adolescents have also used the SSP to obtain sensory-related information about their participants (Dwyer et al., 2020; Van Etten et al., 2017; Uljarevic et al., 2016; Wigham et al., 2015). We used the SSP to measure sensory processing across various sensory modalities. Additionally, the GSQ provided information regarding sensory subtypes (i.e., specific hyper- and hypo-sensitivities within the effected sensory modalities) and is intended for use in the general population (Robertson & Simmons, 2012).

The IUS-12 evaluated participants’ reaction to unpredictable life events such as the future and ambiguity (Carleton et al., 2007). It is a short-form that was taken from the 27-item original Intolerance of Uncertainty Scale. Participants responded using a five-point Likert scale and were measured on two factors of IU—prospective and inhibitory IU. The IUS-12 was selected for our study as a measure of behavioral prediction difficulties.

The SQ and EQ assessed the levels of systemizing and empathizing capability within study participants (Baron-Cohen et al., 2003; Baron-Cohen & Wheelwright, 2004). Both are a 60-item self-reported questionnaire intended for adults with normal levels of intelligence. A scale of ‘Definitely Agree—Slightly Agree—Slightly Disagree—Definitely Disagree’ was used to answer each item. The surveys included 40 questions each that assessed empathizing and systemizing with 20 questions each that distract from the assessment focus. In the initial study, results of the EQ were inversely correlated with scores on the AQ in autistic and NT adult subjects (Baron-Cohen & Wheelwright, 2004). These surveys were selected for the current study to address behavioral traits in the NT population that are commonly associated or disassociated with autism.

The BAPQ and AQ assessed the presence of autistic traits in survey participants (both autistic and NT). For example, the AQ assessed social skills, attention to detail, attention switching, communication, and imagination (Baron-Cohen et al., 2001; Robertson & Simmons, 2012). The
BAPQ was designed to target the general population, so it focused on the primary components of the BAP: aloofness, rigid personality, and pragmatic language difficulties, in addition to the domains addressed by the AQ (Hurley et al., 2007). Both questionnaires were self-report and utilized a Likert scaling method for each question/statement. These surveys were identified for the current study as measures of autistic traits in the NT population.

The DASS-21 is a 21-item self-reported questionnaire that addressed feelings of depression, anxiety, and/or stress in each participant (Lovibond & Lovibond, 1995). This is a shortened version of the DASS-42. Answers to each question applied to the participant’s feelings over the past week and were rated using a Likert scale of 0-3. Repeated research has demonstrated that the DASS-21 is a reliable and valid measurement of depression, anxiety, and stress (Antony et al., 1998; Henry & Crawford, 2005). This survey was used in the current study to measure levels of anxiety, stress, and depression as they related to the presence of sensory processing and autistic traits in study participants.

Volunteers spent approximately 30-60 minutes completing the online survey. Lastly, participants were asked to share, if they felt comfortable, diagnostic status related to ASD, anxiety, and ADHD for themselves and their immediate family members. If subjects were interested in participating in Phase 2 of the study that involved rs-fMRI testing (see Phase 2), we asked for permission to contact them regarding future participation. Subjects were offered compensation in the form of a drawing for one of several gift cards for completing the survey portion of the study.

**Data Analysis**

The relationships between scores on the aforementioned surveys were assessed by carrying out planned partial correlations, controlling for sex, assuming normal score distribution. In some cases, we used multiple complimentary measures to examine the same construct (e.g., the SSP and GSQ both measure sensory processing abilities). Correlations were carried out between each of
these assessments and the measure(s) of the other paired constructs. Overall, we performed similar correlational analyses between the total scores, and subtest scores, on all above-mentioned surveys. Other partial correlations were performed to identify the influence of potentially confounding variables on total score results including year in school (i.e., freshman, sophomore, junior, senior), age, and grade-point average (GPA).

Additionally, we performed between groups comparisons of means using one-way ANOVA to evaluate any difference between pairings of several groups within our sample. For instance, we investigated differences in questionnaire total scores for field of study by grouping majors into their respective colleges (i.e., business, engineering, fine arts and communication, education, humanities, life sciences, physical and mathematical sciences, family, home, and social sciences, nursing, and undeclared). Additional post hoc testing discovered how significant these differences in total scores were from one college to the next. Multiple comparisons correction was applied to all correlation and comparison results via the False Discovery Rate (FDR) method ($q = .05$).

Finally, we completed two-step cluster analysis to test the ability of our measures to classify participants into groups related to their behavioral characteristics and relatives’ diagnoses. Standardized total scores of all measures were used as continuous variables along with a categorical variable of first-degree relative diagnosis of ASD. One-way ANOVA was also used to verify cluster-based group differences.

**Phase 2: Relationships Between Behavioral Sensory Processing, Autistic Traits, and Related Characteristics and Their Neurophysiologic Correlates in Neurotypical Young Adults**

**Participants**

We recruited 60 (35 female) NT individuals from Phase 1 of the study to participate in Phase 2, which involved rs-fMRI testing. While all 60 individuals were scanned, five subjects were eliminated from analysis due to pre-processing difficulties with their images (e.g., data
contamination, excessive movement) as is common in many fMRI studies. In particular, we built the sample to target a variety of ages, races/ethnicities, comorbid diagnoses of ASD, anxiety, and ADHD, university majors, and GPA’s.

**rs-fMRI Acquisition Procedures**

In Phase 2, each participant underwent an approximately 30-minute set of four scans (i.e., field-mapping, localizer, structural MRI, rs-fMRI). During fMRI acquisition, participants were asked to remain awake/alert, keep still, and hold their gaze on a fixed black-and-white cross. A 3T Siemens Trio MR scanner housed on the Brigham Young University campus was used for all scans. Whole-brain blood oxygen level-dependent (BOLD; i.e., brain activity measured by the distribution of blood flow throughout the brain) datasets, in addition to anatomical MRI scans, were collected for each subject using the following parameters: 40 axial slices, 2.5 mm thick with 0.5 mm gap, 220 mm 2 fov 64 squared matrix = 3.43 mm 3 voxels, repetition time = 2500 ms, echo time = 30 ms. Additionally, a T1-weighted anatomical scan (MP-RAGE) was obtained for co-registration and normalization to Montreal Neurological Institute (MNI) space for each participant.

**rs-fMRI Data Analysis**

All structural and functional scans were pre-processed to eliminate the effects of motion and other artifacts that distorted the images. Rs-fMRI data then underwent independent component analysis (ICA) within the Conn toolbox (Whitfield-Gabrieli & Nieto-Castanon, 2012), run through Matlab (MathWorks, 2011). Independent component (IC) networks related to our hypotheses (i.e., sensory, supramodal, and large-scale distributed networks) were chosen from the initially computed ICs. Selection and naming of ICs was aided by a spatial match to template using several template networks contained within Conn, as well as the 10 common ICs reported in Smith et al. (2009) and the 14 resting state functional networks reported in Shirer et al. (2012). Other ICs that contained artefact or biological networks that did not match our hypotheses were discarded in order to decrease
noise and increase statistical power. We then calculated the functional network connectivity within and between brain networks of interest. The strength of functional connectivity was determined by computing correlations of the brain activity between these ROIs. We applied an FDR correction of $q = .05$ to all functional connectivity measurements. We reasoned that those areas displaying high degrees of correlation between their BOLD responses were working together as a network, or were functionally connected, and vice versa. Then, associations between functional connectivity and behavioral results (see Phase 1) were evaluated via correlation analysis. These findings were overlayed onto their structural/anatomical images to create figures that illustrated the neural correlates of our behavioral constructs. Finally, we employed two-step cluster analysis, using standardized total scores from all behavioral measures to explore grouping Phase 2 participants by degree of autistic traits, sensory processing difficulties, and related behaviors. Cluster-based groups were then used as a variable to evaluate between-groups differences in functional connectivity for each IC network. Partial correlations were then computed between group functional connectivity differences and behavioral measures to assess brain-behavior relationships.

Note that investigators, Savanah Calton (SC) and Garrett Cardon (GC), contributed in equitable ways to the current project. For instance, both equally contributed to the initial conceptualization and design of the study. SC completed the lion’s share of the data collection, with GC’s guidance and assistance. Also, while most of the writing was carried out by SC, GC performed much of the analysis with SC’s input and assistance. Though each person had their specific roles, the team functioned in an agreed upon, fair, and productive manner.

Results

The current study was devised to explore the behavioral and neurophysiologic relationships between sensory processing, autistic traits, and other pertinent behavioral correlates in NT emerging adults. To accomplish this, we first calculated the total and subtest (where applicable) scores for
each behavioral questionnaire (i.e., BAPQ, AQ, SSP, GSQ, IUS-12, SQ, EQ, and DASS-21). These scores were then used in partial correlations controlling for sex across all participants, between group comparisons, and two-step cluster analysis. After completing these computations, we performed rs-functional connectivity analysis of a subset of participants ($n = 60$) to determine which brain activity patterns were associated with scores on the above measures.

**Sensory Processing and Autistic Traits**

We observed significant degrees of sensory difficulty in a large portion of the sample. Approximately 66% of study participants fell into the “probable difference” or “definite difference” categories of the SSP. Roughly 36% of participants fell specifically into the “definite difference” category. Thus, descriptive analysis of the SSP revealed that a majority of NT participants reported notable levels of difficulty with sensory processing (see Figure 1).

In addition, a portion of our NT participants provided results above the cutoff scores for the BAPQ and AQ measures of autistic traits (see Figure 2). According to the BAPQ, using a cutoff score of 3.47 (Sasson et al., 2013), 16.9% of our sample expressed significant autistic traits. Approximately 7% of our sample showed elevated levels of autistic traits on the AQ (using a cutoff score of 29; Broadbent et al., 2013).

Partial correlations of the total scores of measures of sensory processing and measures of autistic traits revealed that as sensory processing difficulties increased participants also exhibited a higher degree of autistic traits. For example, the SSP (lower scores reflect poorer sensory processing) showed a significant negative correlation with the BAPQ ($r = -.487, p < .001$) and the AQ ($r = -.414, p < .001$). Likewise, the GSQ was significantly correlated with the BAPQ ($r = .45, p < .001$) and AQ ($r = .41, p < .001$; see Figure 3).

We carried out similar analyses for the subtests of the SSP to investigate the relationship between specific types of sensory processing differences and autistic traits. We observed several
notable associations between these factors. For instance, the Auditory Filtering subtest showed a significant negative relationship with the BAPQ total score ($r = -.412, p < .001$). In addition, the GSQ Hypersensitivity subtest exhibited a significant relationship with the BAPQ total score ($r = .48, p < .001$). Analysis of the BAPQ subtests demonstrated that Pragmatic Language was strongly associated with the SSP total score ($r = -.5, p < .001$). The Rigidity subtest had a similar finding with the SSP total score ($r = -.43, p < .001$). The BAPQ subtest of Pragmatic Language was also strongly correlated with the GSQ total score ($r = .49, p < .001$).

**Psychiatric Difficulties**

Sensory processing also showed significant correlations with psychiatric difficulty, in that, overall, less favorable sensory processing scores were related to increased psychiatric difficulty. For instance, total scores on the SSP demonstrated a significant correlation with the DASS-21 total score ($r = -.52, p < .001$). The GSQ showed a similar correlation with the DASS-21 ($r = .56, p < .001$; see Figure 4; see Table 1). In addition to running correlations between the total scores of each measure, we evaluated the associations between the subtests of the DASS-21 and the total scores of the SSP and GSQ. While these results were significant, none were appreciably stronger than the total score correlations.

We also compared measures of autistic traits with the DASS-21 and found a similar relationship to measures of sensory processing and the DASS-21. The BAPQ displayed a significant correlation with the DASS-21 ($r = .5, p < .001$), as did the AQ ($r = .43, p < .001$). Subtests of the DASS-21 were also correlated with total scores of the AQ and BAPQ. Results of these correlations were similar to the findings with the sensory measures—significant but not noticeably stronger that the total score correlations. Overall, these findings suggest that participants who reported more severe scores on measures of sensory processing also reported less favorable scores on measures of autistic traits and psychiatric difficulty.
**Intolerance of Uncertainty**

The IUS-12 total score correlated with measures of sensory processing, autistic traits, and psychiatric illness. Partial correlations between the IUS-12 and measures of sensory processing revealed that as IUS-12 scores increased there were higher reports of sensory processing difficulties (see Figure 5). For example, the SSP showed a significant negative correlation with the IUS-12 \( (r = -0.535, p < .001) \). The GSQ also had a significant correlation with the IUS-12 \( (r = 0.51, p < .001) \). A similar relationship was found between IU and autistic traits as represented in the correlations between the IUS-12 and BAPQ \( (r = 0.58, p < .001) \) and the IUS-12 and AQ \( (r = 0.54, p < .001) \). The DASS-21 also displayed a significant correlation with the IUS-12 \( (r = 0.55, p < .001) \). Therefore, partial correlations between the IUS-12 and each of the above measures revealed that heightened IUS-12 scores are significantly correlated with increases in sensory processing difficulties, expression of autistic traits, and psychiatric difficulty in NT young adults.

**Empathizing and Systemizing**

Overall, the partial correlations between the EQ and other questionnaires tended to be stronger than the correlations between the SQ and other measures. For instance, the EQ and BAPQ \( (r = -0.59, p < .001) \) and the EQ and AQ \( (r = -0.51, p < .001) \) showed significant negative associations—i.e., in general, EQ was lower in those with higher degrees of autistic traits. Other correlations between behavioral measures and the EQ, which were weak, yet significant, are shown in Table 1.

**Demographics-Based Partial Correlations**

In addition to the direct correlations completed between our standardized measures, we computed partial correlations for a variety of other variables including year in school (i.e., freshman, sophomore, junior, and senior), age (i.e., 17 to 26), and GPA (i.e., 0.0-4.0). Sample demographics can be seen in Table 2. Each of these items were tested against the total scores for each
questionnaire. Overall, we found that none of these variables showed significant relationships with questionnaire scores.

**College Major**

One-way ANOVA, evaluating between group differences in SSP total score, across groupings of college major, revealed a significant main effect of group (F = 1.98, p = .038).

Additionally, post hoc testing revealed that the scores of those in the education group (n = 111; M = 150.9, SD = 18.4) differed significantly from those in the fine arts and communications group (n = 70; M = 141, SD = 17.3; p = .016; see Table 3; see Figure 6). We also found a significant main effect of group in GSQ total score (F = 3.1, p < .001). Post hoc testing revealed significant contrasts between the scores of those in the education group (M = 36.2, SD = 18.3) and those of students in the family, home, and social sciences (n = 266; M = 45.7, SD = 19.7; p < .001), fine arts and communications (M = 46.3, SD = 15.7; p = .016), life sciences (n = 250; M = 45.1, SD = 18.3; p < .001), physical and mathematical sciences (n = 82; M = 46.2, SD = 18.9; p = .009), business (n = 121; M = 45.9, SD = 19.9; p = .003), and none/undeclared major (n = 154; M = 46.4, SD = 17.2; p < .001) groups.

One-way ANOVA was also performed between group differences in measures of autistic traits. The BAPQ total score demonstrated a significant main effect of group (F = 5.46, p < .001). Further post hoc testing showed that the scores of those in the education group (M = 2.8, SD = 0.5) differed significantly from those in the engineering (n = 100; M = 3.1, SD = 0.6; p = .002), physical and mathematical sciences (M = 3.2, SD = 0.7; p < .001), and none/undeclared major (M = 3, SD = 0.6; p = .017) groups. In addition, the engineering (M = 3.1, SD = 0.6) and family, home, and social sciences (M = 2.8, SD = 0.6, p = .014) groups significantly differed. The physical and mathematical sciences (M = 3.2, SD = 0.7) also significantly contrasted with the family, home, and social sciences (M = 2.8, SD = 0.6; p < .001), life sciences (M = 2.9, SD = 0.5; p = .016), and business (M = 2.9,
SD = 0.6; \( p < .001 \) groups. The AQ total score demonstrated a significant main effect of group as well (\( F = 7.1, p < .001 \)). Post hoc testing for this measure showed that those in the education group (M = 15.7, SD = 6.3) differed significantly from those in the engineering (M = 20.7, SD = 6.8; \( p < .001 \)), life sciences (M = 18.6, SD = 6.1; \( p = .005 \)), physical and mathematical sciences (M = 21.7, SD = 8.2; \( p < .001 \)), and none/undeclared major (M = 18.8, SD = 6.7; \( p = .01 \)) groups. The physical and mathematical sciences group (M = 21.7, SD = 8.2) also significantly differed from the business (M = 17.9, SD = 5.7; \( p = .003 \)), family, home, and social sciences (M = 17.2, SD = 6.4; \( p < .001 \)), fine arts and communications (M = 18.1, SD = 6; \( p = .033 \)), life sciences (M = 18.6, SD = 6.1; \( p = .011 \)), nursing (n = 57; M = 17.3, SD = 7.7; \( p = .005 \)), and none/undeclared major (M = 18.8, SD = 6.7; \( p = .049 \)) groups. Engineering (M = 20.7, SD = 6.8) and the family, home, and social sciences (M = 17.2, SD = 6.4; \( p < .001 \)) groups also had significant differences.

We also performed one-way ANOVA for the DASS-21 Anxiety subtest score. This also revealed a significant main effect of group (\( F = 2.25, p = .017 \)). Within this subtest, only one post hoc test was shown to have a significant difference between groups—education (M = 7, SD = 7.1) and the family, home, and social sciences (M = 10.6, SD = 9.3; \( p = .007 \)) groups.

Interestingly, various significant differences between college major-based groups also existed with the EQ and SQ. One-way ANOVA evaluating the differences between college major in EQ and SQ showed significant main effects of group for scores on both questionnaires (EQ: \( F = 11.01, p < .001 \); SQ: \( F = 21.16, p < .001 \)). Post hoc evaluation of specific differences between each major showed several notable patterns. For instance, education and family, home, and social sciences majors tended to show a pattern of high EQ, with low SQ scores. In contrast, people from the engineering and physical and mathematical sciences majors presented with high SQ and lower EQ scores, on average. Those from fine arts and communications majors, in general, exhibited low SQ scores, but also didn’t show EQ scores that were as high as others with low SQ scores (e.g.,
education and family, home, and social sciences). Means, standard deviations and statistical
differences between these groups can be seen in Table 3 and Figure 7.

First-Degree Relatives With ASD vs. Without

We performed a two-step cluster analysis in those with either self-reported autistic first
degree relatives or those with no reported relatives on the spectrum \( n = 164 \). The analysis included
all standardized total scores as continuous variables and “first-degree relative diagnosis of ASD” as
a categorical variable to test the ability of our measures to classify participants into groups related to
their behavioral characteristics and relatives’ diagnoses. The model classified participants into
groups with “fair” accuracy (average silhouette = 0.4). Cluster one \( n = 46 \) was entirely composed
of participants who had first-degree relatives with a diagnosis of ASD. In this group, the average
total scores on each measure were as follows: BAPQ (M = 2.6), AQ (M = 13.9), IUS-12 (M = 24.6),
DASS-21 (M = 21.3), GSQ (M = 39.7), EQ (M = 49.1), and SQ (M = 23.8). Cluster three \( n = 83 \)
was made up of 100% participants who reported no first-degree relatives with a diagnosis of ASD.
The average total scores in this group were similar to those in cluster one—BAPQ (M = 2.8), AQ
(M = 16.6), IUS-12 (M = 27.4), DASS-21 (M = 29), GSQ (M = 39.8), EQ (M = 45.4), and SQ (M =
24.6). The second cluster \( n = 35 \) was comprised of a majority (79.5%) of people who reported
having first-degree relatives with a diagnosis of ASD. The analysis revealed that on average, cluster
two had significantly less favorable total scores on all measures—BAPQ (M = 3.6), AQ (M = 25.5),
IUS-12 (M = 37.3), DASS-21 (M = 53.1), GSQ (M = 59.1), EQ (M = 37.1), and SQ (M = 29.3)—
compared to clusters three and one. One-way ANOVA, with a post hoc Bonferroni test, showed that
the cluster with the least favorable scores (cluster two) differed significantly from the other two
clusters on all mean total scores, while the other clusters did not differ from each other (see Table 2
and Figure 8).
rs-fMRI Functional Connectivity Analysis

Within Group Connectivity

The second phase of our study involved a functional network connectivity analysis within a subset of the participants drawn from Phase 1. The remaining sample was composed of 23 males and 32 females (demographic factors and mean and standard deviations for behavioral measures can be seen in Table 4). After completing group ICA to determine brain networks of interest, network connectivity within the entire group was completed related to autistic traits and sensory processing (all significant network connectivity findings can be seen in Supplementary Data). Notably, we identified a pattern of network connectivity between the salience network (IC12) and bilateral pre and postcentral gyri (esp. R; T = 5.08, \( p < .001 \)), which was significantly associated with several of our behavioral measures—i.e., AQ (\( p < .001 \)), BAPQ (\( p < .001 \)), GSQ (\( p < .001 \)), GSQ Hypersensitivity (\( p < .001 \)). Further correlation analysis to assess the strength of the brain-behavior correlations revealed that the above pattern of connectivity was especially strong for the AQ total score (\( r = .59; p < .001 \)) and GSQ Hypersensitivity subtest score (\( r = .45; p < .001 \)) across all NT participants, such that increased connectivity was associated with less favorable scores (see Figure 9).

Between Clusters Connectivity-Based Differences

We also completed a second cluster analysis in the aforementioned subset of participants using the standardized (z) total scores from all behavioral measures as continuous variables (see Figure 10). This analysis divided our group into two clusters with fair accuracy—a cluster (\( n = 28 \)) with typical scores on all measures and another cluster (\( n = 27 \)) with significantly less favorable scores (see Table 4). Then, we used cluster information to group Phase 2 participants to perform further network connectivity analysis comparing network connectivity between those with fewer vs. individuals exhibiting more autistic traits. Connectivity between a sensorimotor/cerebellar network...
(IC39) and bilateral supramarginal gyri (esp. R) was significantly different between the mild and severe clusters (mild < severe; T = 4.29; p < .001). This pattern of connectivity was positively correlated with AQ (r = .42; p = .002) and IUS-12 (r = .42; p = .002) total scores across all NT participants, such that increased connectivity was associated with less favorable scores (see Figure 11).

**Discussion**

The current study aimed to examine autistic traits and related behaviors in NT young adults. In addition, we investigated the neurobiological underpinnings of these behavioral constructs. We hypothesized significant associations between measures of autistic traits and the other behavioral domains that we measured and that these behaviors would be correlated with brain activity in sensory networks, the cerebellum, the amygdala, and large-scale resting state networks. Our analysis revealed: (a) significant partial correlations were discovered between all behavioral measures except for measures of systemizing; (b) significant differences in autistic traits and sensory processing between participants in college major-based groups; (c) our sample could be categorized into three distinct groups of individuals via cluster analysis based on similar behavioral measure scores. One cluster, composed primarily of participants with first-degree relatives on the autism spectrum, was discovered to have significantly less favorable scores on all behavioral measures when compared to the other two clusters; (d) neurophysiologic results that showed that behaviors, such as autistic traits, sensory processing, and IU, were related to network connectivity between the salience, sensorimotor (esp. pre and postcentral gyri), cerebellum, and multimodal association cortices implicated in multisensory integration and social function (e.g., supramarginal gyrus). The following paragraphs will discuss these findings in greater depth.
Sensory Processing and Autistic Traits

One of the clearest findings from our study was the significant relationship between sensory processing difficulties and the presence of autistic traits in the NT population. This finding supports not only our hypothesis that these constructs would be strongly correlated (i.e., as one increased, so would the other), but the results in the current literature. Several researchers have concluded, through behavioral studies similar to our own, that the relationship between sensory processing and autistic traits in NT young adults/adults is similar to the relationship in autistic individuals of the same age (Baren-Cohen et al., 2001; Dwyer et al., 2020; Mayer, 2016; Robertson & Simmons, 2012).

While these results were expected, we didn’t presume that so many of our participants would report such high levels of sensory processing difficulty. This discovery, however, supports the value of dimensional analysis of data pertaining to autism (U.S. Department of Health and Human Services, 2021). In other words, there appear to be complex relationships between traits that are common to autism that exist in both diagnosed and undiagnosed individuals alike. While categorical analysis of these variables can certainly provide meaningful diagnostic information, dimensional analysis might offer unique insights into human characteristics that are continuous and not relegated to one group or another.

Sensory processing and autistic traits seem to be fundamentally connected, regardless of diagnosis. Our findings validate our concern that there is a subset of individuals within the general population who may have above-average difficulty in the areas of sensory processing (i.e., up to 30%) and/or autistic traits (i.e., approximately 7.4-16.9%, depending on the measure used), but may not be aware of the source(s) of or connections between their difficulties. The discrepancy in percentage of autistic traits expressed in our NT sample may be attributed to the slightly different nature and focus of each autistic traits measure that we used. The BAPQ was designed to measure
the BAP, while the AQ was devised as a screening tool to identify individuals who might need a more comprehensive diagnostic assessment. Regardless, there is a significant portion of our sample that showed elevated levels of autistic traits. Without diagnoses, these people are most likely unable to access services/accommodations that would support them in their challenges. However, the present, dimensional findings advance the notion that those without a formal clinical diagnosis could potentially benefit from support.

In addition to the aforementioned, we identified several other interesting findings upon delving deeper into the relationship between sensory processing and autistic traits in our study. For instance, analysis of the subtests of these measures showed that auditory filtering sensitivity and hypersensitivity were associated with the presence of greater degrees of autistic traits overall. The current literature indicates that auditory issues are some of the most common sensory difficulties that autistic individuals experience (Baum et al., 2015; Demopoulos & Lewine, 2016; Kuiper et al., 2019). Specifically, autistic people commonly have auditory sensitivities and difficulty with understanding in the presence of noise and filtering out unwanted signals (Marco et al., 2011; Schauder & Bennetto, 2016; Thye et al., 2017). In conjunction with auditory sensitivity, general hypersensitivity, as measured with the GSQ, may be related to the lack of ability to filter out unwanted signals and attend to desired stimuli, a finding very common in autism.

Another strong correlation we observed concerned pragmatic language scores and total scores on sensory measures. Recent studies have reported connections between sensory processing and multiple aspects of language, including pragmatic language (Ronconi et al., 2016). For instance, in unpublished data from our lab, semantic language impairments were shown to be significantly associated with sensory processing difficulties (Cooper, 2021). Additionally, Thye et al. (2017) have presented evidence of the relationship between deficits in social communication/pragmatic language and atypical sensory processing. One important aspect of this relationship may be sensory
prediction. Much of social function relies on one’s ability to predict what other people are thinking, feeling, and/or about to say. This function is built on the ability to appropriately process and predict sensory inputs—visual inputs like facial expressions and gestures, auditory inputs like voice inflection/prosody (sometimes very subtle), etc. The connection between sensory processing and pragmatic (and other facets of) language suggests its fundamental contribution to the social communication aspect of autism diagnostic criteria. In the present study, the correlation between sensory processing and intolerance of uncertainty, as well as the associations between these factors and pragmatic language hint at the interaction between sensory processing, prediction, and social communication.

**Psychiatric Difficulties**

Psychiatric difficulty was another behavioral construct we investigated in terms of its ties to sensory processing and autistic traits. Consistent with our hypothesis, we discovered that increased levels of sensory sensitivity and autistic traits were both positively associated with psychiatric difficulty in NT emerging adults. We also hypothesized that, specifically, anxiety would be increased relative to other psychiatric manifestations such as stress and depression. However, our results didn’t show that one psychiatric difficulty was more strongly correlated to sensory processing and autistic traits than the others.

The current literature on related topics also states that psychiatric difficulty is linked to increased sensory sensitivity and autistic traits. In these studies, anxiety is the primary difficulty shown to be increased in all age groups of autistic individuals (Boulter et al., 2014; Dunn et al., 2016; Dwyer et al., 2020; Green et al., 2012; Lau et al., 2020; Lin & Huang, 2019; South & Rodgers, 2017; Syu et al., 2020; Uljarević et al., 2016; Wigham et al., 2015). Our findings add to these reports by showing that both stress and depression may also be associated with sensory processing and autistic traits. Furthermore, it is important to note that previous studies reported
similar correlations in autistic participants, while our study has focused on NT young adults. These novel findings add to the current body of literature concerning the BAP and underscores the notion that the relationships between autistic traits, sensory processing, and psychiatric difficulty in NT people mirror those seen in autistic individuals.

We also discovered that correlations between sensory measures and the DASS-21 were slightly stronger than those between measures of autistic traits and the DASS-21. This may indicate that psychiatric difficulty is more associated with sensory abnormalities than autistic traits. Because this finding is now demonstrated in the NT population, it is reasonable to believe that the impact of both sensory sensitivity and autistic traits on emotional health can be expanded beyond those with an autism, ADHD, traumatic brain injury, Schizophrenia, etc. diagnosis. Rather, the concept of the BAP can be actively included in this schema. Supports and accommodations provided during the early adult phase of life, which has already been demonstrated to manifest the most psychiatric difficulty across all individuals (Gadke et al., 2016), could be crucial to improving mental health, educational outcomes, career success, and, perhaps, even alarming suicide rates among this population (Kõlves et al., 2021). Future studies should endeavor to investigate these effects.

**Intolerance of Uncertainty**

IU has been established in the literature as the mediating factor in the relationship between sensory processing difficulties and anxiety (Boulter et al., 2014; South & Rogers, 2017; Wigham et al., 2015). We identified that increased sensory difficulties, high presence of autistic traits, and symptoms of psychiatric difficulty are all individually associated with greater IU in our sample. This finding supports our hypothesis that IU would have a strong positive relationship with each of these behavioral constructs.

Among these correlations, we found the strongest relationship between the IUS-12 and the BAPQ total scores, highlighting the important connection between IU and autistic traits. Several
individuals have advocated the predictive coding model of autism in recent years (Van Boxtel & Lu, 2013; Van de Cruys et al., 2014). According to this model, autistic individuals have difficulty making accurate predictions about the present/future, based on their past experiences. Mismatches between incoming information and the predictions made about them often lead to very unpleasant feelings and reactions (e.g., jumping into a swimming pool that is colder than expected or eating a dish that doesn’t taste or feel like what was predicted; Boulter et al., 2014; Tam et al., 2017; Wigham et al., 2015). This type of difficulty, if experienced regularly over the long term, could lead to an aversion to unpredictable situations, or an intolerance of uncertainty. Furthermore, it is logical to believe that development of this type of aversion might be associated with increased levels of autistic traits including rigidity, insistence on sameness, and theory of mind difficulties (Boulter et al., 2014; D’Mello & Stoodley, 2015; South & Rodgers, 2017; Tam et al., 2017; Wigham et al., 2015).

Pertinent to the current study, we also observed that sensory processing was significantly correlated with IU. In the same way that prediction difficulties could be connected to the development of autistic traits, mismatches between sensory inputs and related predictions could also be related to atypical sensory processing (South & Rodgers, 2017; Wigham et al., 2015). Either informing attempted predictions with atypical sensory information or making inaccurate predictions about sensory inputs could result in sensory prediction errors and could contribute to many of the sensory behaviors observed in autistic individuals. The present data suggest that these effects may vary across those who don’t have a diagnosis of ASD as well and may further elucidate an important behavioral correlate of sensory processing atypicality. Such behavioral connections may also have complimentary neurobiological underpinnings (Cardon, 2018; Cardon et al., 2017). Perhaps, because of the above, there is potential to help alter the influence this trait has on individuals either through reducing uncertainty or increasing tolerance for uncertainty in life situations for affected individuals.
Despite the strong relationships between these variables, it is still difficult to pinpoint exactly where each of these constructs intersects. The question remains if these relationships are all completely independent of each other or deeply connected to one another. To solve this issue, further, more complex, analysis of these variables should be completed to identify/parse out the specifics of relationships between autistic traits, sensory processing, psychiatric difficulty, and IU.

**Empathizing and Systemizing**

Our results also revealed that, in general, as an individual’s ability to empathize increased there was a decrease in the degree of autistic traits that they possessed. Systemizing behavior, however, was not strongly associated with any behavioral construct. We originally hypothesized that systemizing behavior would be strongly positively associated with the other constructs and that empathizing would be strongly negatively associated with the same. Though the relationship between empathizing and autistic traits was consistent with our hypotheses, our findings related to systemizing were not. These findings differ somewhat with the current literature on systemizing’s relationship to autistic traits and sensory processing. For instance, Tavassoli et al. completed a behavioral study in 2017 that evaluated the relationship between empathizing and systemizing skills, autistic traits, and sensory symptoms in autistic and typically developing children and children with sensory processing disorder. Results demonstrated that the autistic children displayed generally low empathizing skills, high systemizing skills, and the greatest degree of sensory difficulties compared to other groups. Our results concerning empathizing parallel the literature which states that high presence of autistic traits is in opposition to empathizing behavior (Baron-Cohen et al., 2003; Tavassoli et al., 2017). On the other hand, the discrepancy between the current findings and the study cited above may represent a difference between diagnosable ASD and the BAP or autistic traits across the lifespan. Similarly, systemizing behaviors may not be characteristics to target first when attempting to alleviate the sensory difficulties associated with autism.
Despite the lack of significant findings concerning these measures, our cluster analysis revealed a significant increase in SQ scores and decrease in EQ scores for participants in cluster two, which was composed of participants who had the least favorable scores on all behavioral measures. This may speak to the relationship between these variables and higher levels of autistic traits, sensory processing difficulties, and psychiatric health, which aligns with the literature concerning these relationships in autistic individuals. Once again, this may point to a difference between diagnosable ASD and the BAP in the NT population.

Similarly, individuals in the engineering and physical and mathematical sciences college major groups exhibited significantly elevated systemizing quotients and decreased empathizing tendencies. In contrast, those from education and family, home, and social sciences related majors showed the opposite pattern of empathizing and systemizing. Interestingly, people that identified as fine arts majors showed increased empathizing, but significantly lower systemizing quotients, while also showing heightened autistic traits and sensory difficulties. While the first two patterns are consistent with previous literature, the latter (fine arts) present an alternate profile. This finding underscores the idea that there are various subtypes of autism—i.e., in the presence of elevated autistic traits, other autism-related factors (e.g., sensory processing, empathizing, systemizing) can differ greatly across the population. Moving forward, dimensional analysis of peoples’ numerous characteristics will likely be important when considering how to support them clinically.

**Demographics-Based Partial Correlations**

In addition to our primary behavioral constructs, we evaluated the impact of other potentially confounding variables on our sample. Participant year in school and/or age did not demonstrate a significant relationship(s) with total questionnaire scores. While we didn’t hypothesize a specific outcome concerning these variables, we planned to test for their effects on our sample due to their potentially confounding nature. Our results demonstrate that these variables actually have no
significance concerning total scores on our surveys. A majority of autism research has been
completed on infants, toddlers, and children. Our study is one of few to investigate these
relationships in this age group in NT individuals. One study of NT college students and the general
population testing the validity of the AQ also found that participant age showed no significant
relationship to presence of autistic traits (Hoekstra et al., 2008). In a way, the absence of any finding
concerning participant age may support the ruling out of older theories stating that sensory
processing difficulties don’t continue across the lifespan. Several more recent studies have
concluded similar findings to our study, in that age has no determination on presence of autistic
traits or sensory processing difficulties (Crane et al., 2009; Tomchek & Dunn, 2007; see also Dwyer
et al., 2020 & Mayer, 2016).

**College Major**

When analyzing between-groups comparisons across college major-based groups, we
discovered significant main effects of group in both sensory processing and autistic traits. We
collected this information as part of our demographic profile for each participant to help ensure we
collected a diverse and representative sample of emerging adults. Therefore, no particular
hypotheses were created concerning the effects of college major on behavioral total scores.
However, unofficial assumptions were made that particular areas of study such as those focused on
hard sciences, engineering and mathematics, and art would attract students with higher levels of
autistic traits and sensory processing difficulties due to their requirement for strong systemizing
skills and decreased focus on strong social/pragmatic personal qualities. These assumptions were
found to closely align with the results demonstrated in our study.

There is some literature to support that NT students enrolled in a pure or applied science
degree over humanities or social sciences have a stronger presence of autistic traits (Baron-Cohen et
al., 2001; Dell’Osso et al., 2021; Hoekstra et al., 2008). For instance, on subtests of the AQ, science
students reported stronger attention to detail skills and weaker social interaction skills (Hoekstra et al., 2008). This aligns with autism literature regarding strong systemizing skills and low empathizing skills in autistic people (Tavassoli et al., 2017).

Interestingly, total scores of participants in the education group in the current study significantly differed from a variety of other majors in several behavioral constructs including sensory processing, autistic traits, and psychiatric health. Descriptive statistics revealed that the education majors demonstrated the lowest levels of autism-related behavior in all of our measured constructs. In contrast, physical and mathematical sciences and fine arts and communication majors were always included in the highest levels of scores for each construct. While the total scores of the family, home, and social sciences group were typically patterned like those in education, these groups greatly differed on the DASS-21 Anxiety subtest (with family, home, and social sciences demonstrating heightened anxiety scores). The family, home, and social sciences college is composed of anthropology, family life, economics, geography, history, political science, psychology, social work, and sociology. While these results may appear counterintuitive, one study claims that social sciences, such as those listed above, are often chosen more often than hard sciences by those with higher levels of autistic traits (Wei et al., 2013). The combination of historical and hard sciences may appear to attract more of such individuals than previously assumed (Wei et al., 2013).

Participants with education as their declared major showed the lowest scores of autistic traits and sensory processing, yet, in many cases, these individuals will become professionals who will work with, evaluate, and study autistic individuals and others that have similar behavioral traits. It may be valuable to consider that the theories revolving around the lack of empathy that autistic people supposedly have originated from and been promoted by individuals who may find it the most challenging to empathize with their target population, because of their lack of autistic trait
expression. This two-way empathy difficulty—i.e., autistic peoples’ common difficulty empathizing with NT people, as well as NT peoples’ challenge empathizing with autistic people—has been termed the Double Empathy Problem (Milton, 2012). As such, it may be worthwhile to incorporate content related to the Double Empathy Problem into curricula designed to train those going into educational and other related fields. Doing so may increase awareness and appreciation for the empathic abilities and desires of autistic people and facilitate understanding between educators and their autistic students.

Natural groupings of students and traits along college majors provide a unique opportunity to observe and assist students with their particular difficulties and/or strengths. In reference to the Double Empathy Problem, if students are already grouped with other students that have similar behavioral traits to their own, this may provide an environment that is conducive to their learning preferences and styles. Honing in on this finding may actually enhance college experiences for each student and help those struggling to identify their major/area of interest according to their inherent strengths and challenges. Additionally, considering these behavioral constructs during the process of major selection could lead students to majors in which their talents are showcased and amplified for their benefit and that of future employers and society.

First-Degree Relatives With ASD vs. Without

Our sample was classified via cluster analysis into three distinct clusters, with one cluster, that was primarily composed of participants with autistic first-degree relatives, demonstrating significantly less favorable total scores on all measures when compared to the other two groups. While not directly hypothesized, we completed this statistical analysis because of related claims in the current literature. Studies have shown that there is a higher likelihood of immediate family members of autistic persons to exhibit autistic traits and sensory difficulties due to their close blood relation (Constantino & Todd, 2003; Gerdts & Bernier, 2011; Hallmayer et al., 2011; Landry &
Chouinard, 2016; Narayan et al., 1990). Additionally, since most of the behavioral measures used in the current study were significantly correlated with each other, we performed this cluster analysis as a way to investigate their interrelatedness in a more holistic way and determine whether these connections were tied to family-based factors. Our results suggest that while not all who have first-degree relatives on the autism spectrum exhibit elevated autistic traits, the majority (~74%) of those who present with such behavioral tendencies do have close autistic relatives. This finding lends support for genetic accounts of autism, but highlights the notion that other factors (e.g., environmental, developmental, epigenetic) may contribute to autistic trait expression as well.

Furthermore, this finding supports the BAP by demonstrating that while initial studies restricted research of autistic traits and sensory difficulties in the NT population to solely first-degree relatives, there is scientific basis for these claims to address the milder presence of these traits in the general population as a whole (Landry & Chouinard, 2016; Mayer, 2016; Robertson & Simmons, 2012).

Overall, while our results were significant and consistent with the literature, it is important to note that our cluster analysis was limited to 164 participants.

**Neurophysiologic Underpinnings of Sensory Processing and Autistic Traits**

Our neurophysiologic analysis revealed that increased connectivity between salience and pre/postcentral gyri were related to the degree to which both autistic traits and sensory difficulties are expressed across the population. Overall, these results support the notion that autistic traits and sensory processing may share common brain mechanisms that include brain areas important for detecting/determining salient sensory inputs and sensorimotor processing and integration. Initially, the salience network was not specifically a primary region of interest to us while creating our hypotheses. However, these findings are consistent with our hypothesis that sensory-related brain regions would have a positive relationship with behavioral measures. Additionally, the salience network has been connected to other large-scale resting state networks, such as the DMN and
executive control network (Menon, 2018), which were hypothesized to be involved in the behaviors examined in the current study.

These findings are also consistent with the research literature concerning the salience network’s role in autism. Several studies have found that hypersensitivity is strongly related to increased functional connectivity between the salience network and sensory-related brain regions (Green et al., 2016; Keehn et al., 2021). Furthermore, over attribution of attention to sensory stimuli can result in increased autistic traits such as restricted and repetitive behaviors, rigidity, insistence on sameness, IU, increased sensory difficulties, emotion recognition, and impairments in social communication/motivation/cognition (Damiani et al., 2019; Keehn et al., 2021; Margolis et al., 2019; Marshall et al., 2020; Toyomaki & Murohashi, 2013; Uddin et al., 2013). This progression of disruption in higher order brain networks leading to effects in behavior, especially impairments in social communication, also supports current research stating that difficulties in autism are not as much an issue of bottom-up processing, but rather of top-down processing and connectivity (Cook et al., 2012; Loth et al., 2010; Maekawa et al., 2011; Roy & Uddin, 2021). Studies targeting the pre/postcentral gyri have also concluded that increased activity in this region is associated with more autistic traits and has often atypical connectivity with additional primary and sensory integration areas (Francis et al., 2019; Lukito et al., 2020; Philip et al., 2012; Sahyoun et al., 2010; Velasquez et al., 2017).

In addition to the salience network and pre/postcentral gyri, our results demonstrated that increased connectivity between sensorimotor/cerebellar and supramarginal brain regions are related to the degree to which autistic traits and IU are expressed across the population. Overall, these results support the notion that autistic traits and IU (i.e., prediction) may share common brain mechanisms that include brain areas important for sensory processing and integration. These findings are consistent with our hypothesis that primary sensory regions and other supramodal areas
(e.g., cerebellum, supramarginal gyrus) would be positively associated with behavioral measures; in this case, IU and measures of autistic traits.

The current literature reflects similar relationships to those found in our study concerning the cerebellum and supramarginal gyrus. While much of the research analyzes the motor functions of the cerebellum, there is basis for its sensory functions as well (Oldehinkel et al., 2019; Volkmar et al., 2004; Wang et al., 2018). Specifically, the cerebellum is critical to multisensory integration, prediction that utilizes sensory information, and response preparation to environmental stimuli (Courchesne & Allen, 1997). Impairments to cerebellar circuits might interfere with social communication (supramarginal gyrus), language, and attention (D’Mello & Stoodley, 2015). Therefore, this increased connectivity is not coincidental. Rather, it could be associated with specific autistic traits such as insistence on sameness and sensory sensitivity which may then be tied to increased IU. These traits and their neurophysiologic correlates may impact successful social communication.

Notably, these results are some of the first findings of their kind—they show a brain network related to autistic trait expression in the NT population. If we infer that in order for successful brain function there must be dynamic connectivity across several regions/networks, then over attribution or hyper/hypo-activation in certain areas may interfere with productive navigation of real-world scenarios that are generally complex and multisensory experiences (Uddin et al., 2013). Therefore, identifying these atypical networks of connectivity (e.g., increased connectivity between salience and pre/postcentral gyri brain regions; increased connectivity between sensorimotor/cerebellar and supramarginal brain regions), that are associated with increased sensory over responsivity and autistic traits, is a large step towards developing biomarkers for objective diagnosis of ASD (Damiani et al., 2019; Francis et al., 2019; Margolis et al., 2019; Uddin et al., 2013). In addition, this knowledge could potentially improve clinical and educational supports that alleviate characteristics.
that interfere with successful daily functioning (e.g., IU, sensory hypersensitivity, social impairments, rigidity, etc.).

**Limitations**

Despite the significant findings obtained in the current study, there are important limitations for the reader to note when drawing conclusions concerning our results. First, our sample of young adults was acquired primarily from Brigham Young University. The make-up of the population of our campus may be different than that of other potential groupings, which could create challenges pertaining to generalization of our results to individuals of similar ages. While we recruited many individuals from other locations for our study, the number from persons local to the greater Provo/Salt Lake City, Utah geographical area outnumbered these people. Thus, our sample may be, perhaps, prone to more psychiatric difficulties than other samples due to the rigorous academic nature of Brigham Young University, surrounding culture, and/or geographical region.

Additionally, the racial/ethnic variety of the region precluded a high degree of this type of diversity, especially for the in-person fMRI scan data. On the other hand, some of our behavioral sample was collected from other regions of the country, which may have allowed greater diversity. To help overcome this challenge, we attempted to diversify the fMRI sample by personally contacting Phase 1 participants of varying racial/ethnic backgrounds to volunteer as subjects. We maintained a spreadsheet of our sample and regularly compared the racial/ethnic profiles of our participants, in addition to other demographics, to ensure as much diversity as possible. These attempts were impacted by the willingness of individuals to respond to, and volunteer for, Phase 2 of our study. Furthermore, these data were collected during the peak of the COVID-19 pandemic which made in-person participation difficult to achieve, increased cancellations/no-shows for scanning appointments, and may have also skewed some findings, especially concerning self-reported psychiatric health or well-being.
In regards to the behavioral data we collected, the order of questions in our questionnaire was not randomized/counterbalanced. This could’ve led to fatigue effects during testing. In addition, each of these questionnaires were self-report rather than actual tasks to be completed while under direct supervision. This may have introduced issues into the data as well such as personal bias or effects of outside influences when answering survey questions. With this in mind, there was no other observation or analysis performed to verify that the answers participants submitted in their surveys were accurate. Each data point, correlation, and conclusion drawn must take this into account. While fMRI is a direct measure, questionnaires are indirect, meaning what kind of relationships should we expect to exist, may have bearing on the strength of the correlations. However, the size of our sample and the fact that many of our results mirror those presented in other studies lends support for the validity of our data.

**Implications for Practitioners and Other Stakeholders**

As a service provider to those on the autism spectrum, understanding neurophysiologic differences between those with and without these characteristics can enhance the services provided to clients. For example, if a speech-language pathologist has a client with sensory processing difficulties and IU that has not been regulated before beginning their appointment, progress may be difficult to achieve during a session. Empathizing with this client by helping meet their sensory needs within scope of practice and referring for/collaborating with other professional services, such as occupational therapy, could increase the effectiveness of treatment in all domains. In addition, service providers can increase their skillsets by learning more about prediction, IU, and anxiety and how to alleviate these characteristics in their patients. This may not only improve treatment within the therapy room but create beneficial strategies for caregivers and other stakeholders that work with these clients at home, school, and other workplaces that may also induce anxiety. Interdisciplinary
collaboration is key in treating each client in order to support them holistically, rather than in each individual domain of their life.

The results of our study provide several implications for practitioners and other stakeholders not only involved with those on the autism spectrum, but for those that work with individuals close to the diagnostic border/exhibiting higher levels of traits within the general population. Knowing that autistic traits and sensory processing difficulties are related to psychiatric health, especially in the young adult age group (Gadke et al., 2016), could prioritize the need to approve and provide accommodations and supports to these individuals during their college years. Results of this study supplied potential places to start identifying students who may be in need—particular colleges/majors that expressed higher trends of autistic traits and sensory processing difficulties. In addition, we must consider who is being employed to help, as we discovered that specific colleges, like education, had the most different results from those in the hard sciences, engineering, and mathematics departments. If practitioners and other stakeholders were able to help alleviate sensory difficulties by providing accommodations, it may also lead to improved IU, rigidity, psychiatric health, and even enhancements in academic/social/personal life.

When discussing the clinical implications of these behavioral relationships on both NT and autistic populations, it is also important to address the Double Empathy Problem (Milton, 2012). This theory states that although autistic individuals seem to have some difficulty empathizing with NT individuals, NT people also have trouble empathizing with autistic people. The idea suggests that, in fact, autistic individuals don’t necessarily have an empathy deficit as is traditionally supposed. Rather, autistic people empathize differently than what is deemed socially typical. Furthermore, they often empathize with other autistic individuals quite well (Chown, 2014; DeThorne, 2020; Milton, 2012; Mitchell et al., 2021). While the findings in our study don’t address the Double Empathy Problem directly, they suggest that several of the traits common to autism are
also experienced by many undiagnosed individuals. Though these traits are experienced to differing degrees and often in diverse combinations when compared to those on the autism spectrum, their continuous nature suggests that NT and autistic people overlap in more ways than a purely categorical model would suppose. From this overlap, it may be possible to build empathy between these groups and, in so doing, simultaneously improve certain elements of society for all involved.

Some researchers have explained that the dissonance between these types of empathy and the impact on normalizing to mainstream empathizing behavior for autistic individuals causes psycho-emotional disablement (Chown, 2014; Milton, 2012). This issue could be related to the increased anxiety/mental health challenges, sensory difficulties, IU, etc. that autistic individuals face (DeThorne, 2020), which may also apply to those who express high degrees of autistic traits, but are not diagnosed. If more NT people understood how to relate or empathize with those on the autism spectrum, it could change the culture and “pressure to survive,” socially speaking, that autistic individuals feel in society. The negative effect this matter has on autistic individuals, however, is not the only issue to consider. Mainstream society is simultaneously losing out on the opportunity to have the full, unhindered, contributions of autistic individuals in the everyday world (Chown, 2014). There are extreme differences in opinion concerning how to address these difficulties in therapy (Milton, 2012). However, having an open mind to changing cultural values and constructs, and learning about and accepting differences, such as empathizing, across neuro subtypes, is a first step to better support, educational, employment, and other practices, and improved quality of life for all.

**Conclusion**

The prevalence of autism has risen to one out of every 54 children born in the United States. In addition, upwards of 90% of those diagnosed with ASD are said to experience sensory difficulty. While these statistics are impactful, our study has demonstrated that sensory processing difficulties, autistic traits, and other related behaviors are highly prevalent in the general population as well,
consistent with the notion of the BAP. These difficulties provide great challenges to those who face them (e.g., psychiatric difficulty), especially in the young adult population. For these reasons, our study aimed to further explore these constructs, both behaviorally and neurophysiologic in nature, to benefit all who personally possess, have loved ones with, or serve those that regularly express these difficulties. Our results revealed that sensory processing, autistic traits, intolerance of uncertainty, psychiatric difficulty, and empathizing quotient all were significantly correlated. Notable patterns of sensory processing and autistic traits (including empathizing and systemizing) were also found across college-major based groups. Furthermore, cluster analysis showed that the majority of people exhibiting the highest autistic-related traits had first-degree relatives on the autism spectrum. Finally, our novel, yet hypothesized, neurophysiologic results indicated that atypical functional connectivity between sensory-related brain regions (i.e., bilateral pre/postcentral gyri) and supramodal brain areas (i.e., bilateral supramarginal gyri, sensorimotor/cerebellar network IC39, and salience network IC12) correlated with elevated total scores of our behavioral constructs. These findings could increase awareness for these challenges to larger communities and identify cerebral networks involved in atypical sensory processing and the presentation of autistic traits that could provide insight into the origins of ASD, improve diagnostic methods, yield brain-based targets for services, and improve the quality of life for all affected individuals, independent of diagnostic status.
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### Table 1

**Partial Correlations for Behavioral Measure Total Scores**

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<tr>
<th></th>
<th>SSP Total Score</th>
<th>GSQ Total Score</th>
<th>BAPQ Total Score</th>
<th>AQ Total Score</th>
<th>IUS-12 Total Score</th>
<th>SQ Total Score</th>
<th>EQ Total Score</th>
<th>DASS-21 Total Score</th>
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<tbody>
<tr>
<td><strong>SSP Total Score</strong></td>
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<td>-.73; &lt;.001</td>
<td>-.49; &lt;.001</td>
<td>-.41; &lt;.001</td>
<td>-.54; &lt;.001</td>
<td>-.07; .017</td>
<td>.24; &lt;.001</td>
<td>-.52; &lt;.001</td>
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<td>.51; &lt;.001</td>
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<td>.18; &lt;.001</td>
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<td>.58; &lt;.001</td>
<td>.04; .123</td>
<td>-.59; &lt;.001</td>
<td>.49; &lt;.001</td>
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<td>.22; &lt;.001</td>
<td>-.51; &lt;.001</td>
<td>.43; &lt;.001</td>
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<td><strong>IUS-12 Total Score</strong></td>
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<td>-.19; &lt;.001</td>
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<td>.08; .04</td>
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<td>(Male=581, Female=653)</td>
<td>(n=83)</td>
<td>(n=35)</td>
<td>(n=46)</td>
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<tr>
<td></td>
<td>(Male=48, Female=35)</td>
<td>(Male=15, Female=20)</td>
<td>(Male=26, Female=20)</td>
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<td>Mean Age</td>
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<td>21.6 ± 1.9</td>
<td>21.4 ± 1.9</td>
<td>21.3 ± 1.6</td>
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<td>GPA</td>
<td>3.7 ± 1.9</td>
<td>3.7 ± 0.7</td>
<td>3.7 ± 0.5</td>
<td>3.7 ± 0.3</td>
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<tr>
<td>BAPQ Total Score</td>
<td>2.9 ± 0.6</td>
<td>2.8 ± 0.4</td>
<td>3.7** ± 0.4</td>
<td>2.6 ± 0.4</td>
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<td>BAPQ Aloof</td>
<td>33.6 ± 10.4</td>
<td>31.0 ± 8.7</td>
<td>45.0** ± 8.6</td>
<td>28.4 ± 8.4</td>
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<td>BAPQ Pragmatic Language</td>
<td>34.2 ± 7.6</td>
<td>33.1 ± 6.9</td>
<td>40.6** ± 6.6</td>
<td>31.2 ± 6.4</td>
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<tr>
<td>BAPQ Rigidity</td>
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<td>36.1 ± 7.2</td>
<td>46.0** ± 7.0</td>
<td>34.9 ± 6.3</td>
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</tr>
<tr>
<td>AQ Total Score</td>
<td>18.3 ± 6.7</td>
<td>16.6 ± 4.5</td>
<td>26.5** ± 5.2</td>
<td>14.1 ± 4.7</td>
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<tr>
<td>SSP Total</td>
<td>146.7 ± 18.0</td>
<td>150.3 ± 18.8</td>
<td>133.6** ± 20.2</td>
<td>152.2 ± 15.6</td>
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<tr>
<td>SSP Tactile Sensitivity</td>
<td>27.5 ± 4.4</td>
<td>27.5 ± 4.7</td>
<td>26.5** ± 4.6</td>
<td>28.6 ± 3.8</td>
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<tr>
<td>SSP Taste/Smell Sensitivity</td>
<td>16.7 ± 3.5</td>
<td>17.1 ± 3.3</td>
<td>15.8** ± 3.4</td>
<td>16.0 ± 4.5</td>
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<td>SSP Movement Sensitivity</td>
<td>11.2 ± 2.7</td>
<td>11.2 ± 2.3</td>
<td>10.5** ± 2.9</td>
<td>11.3 ± 2.2</td>
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<tr>
<td>SSP Underresponsive/Seeks Sensation</td>
<td>26.3 ± 4.5</td>
<td>26.8 ± 5.0</td>
<td>24.1** ± 4.3</td>
<td>27.0 ± 3.8</td>
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<tr>
<td>SSP Auditory Filtering</td>
<td>20.9 ± 4.1</td>
<td>21.8 ± 3.8</td>
<td>17.8** ± 4.0</td>
<td>22.1 ± 3.4</td>
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<td>SSP Low Energy/Weak</td>
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<td>25.5 ± 4.4</td>
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<td>26.2 ± 3.3</td>
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<td>SSP Visual/Auditory Sensitivity</td>
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<td>21.1 ± 3.1</td>
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<tr>
<td>GSQ Total Score</td>
<td>44.6 ± 18.4</td>
<td>40.0 ± 18.9</td>
<td>58.4** ± 20.5</td>
<td>40.2 ± 18.7</td>
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<tr>
<td>GSQ Hypersensitivity</td>
<td>21.7 ± 10.1</td>
<td>19.3 ± 10.9</td>
<td>29.3** ± 12.8</td>
<td>19.5 ± 9.4</td>
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<tr>
<td>GSQ Hyposensitivity</td>
<td>22.9 ± 9.6</td>
<td>20.7 ± 9.7</td>
<td>29.1** ± 9.0</td>
<td>20.7 ± 10.5</td>
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<tr>
<td>DASS Total Score</td>
<td>32.7 ± 23.7</td>
<td>28.5 ± 21.6</td>
<td>55.0** ± 26.9</td>
<td>22.2 ± 15.9</td>
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<tr>
<td>DASS Depression</td>
<td>10.6 ± 9.7</td>
<td>9.8 ± 9.6</td>
<td>19.9** ± 11.5</td>
<td>6.6 ± 6.9</td>
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<tr>
<td>DASS Anxiety</td>
<td>9.2 ± 8.3</td>
<td>7.4 ± 7.3</td>
<td>16.9** ± 9.6</td>
<td>6.7 ± 5.6</td>
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<tr>
<td>DASS Stress</td>
<td>12.8 ± 8.8</td>
<td>11.3 ± 7.9</td>
<td>18.3** ± 9.4</td>
<td>8.8 ± 6.9</td>
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<tr>
<td>IUS Total Score</td>
<td>29.9 ± 9.4</td>
<td>27.2 ± 8.0</td>
<td>37.8** ± 7.3</td>
<td>25.0 ± 7.2</td>
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<tr>
<td>EQ Total Score</td>
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<td>45.4 ± 11.7</td>
<td>37.0** ± 10.6</td>
<td>49.8 ± 9.4</td>
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<tr>
<td>SQ Total Score</td>
<td>25.2 ± 10.9</td>
<td>25.3 ± 9.8</td>
<td>28.5** ± 12.4</td>
<td>24.6 ± 10.6</td>
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**p < .001
### Table 3

**Behavioral Measure Mean Total Scores for College Major-Based Groups**

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<th>Total Scores</th>
<th>Business (n=120) Mean</th>
<th>SD</th>
<th>Education (n=110) Mean</th>
<th>SD</th>
<th>Engineering (n=100) Mean</th>
<th>SD</th>
<th>FHSS (n=260) Mean</th>
<th>SD</th>
<th>Fine Arts &amp; Comm (n=70) Mean</th>
<th>SD</th>
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</thead>
<tbody>
<tr>
<td>BAPQ</td>
<td>2.9</td>
<td>0.6</td>
<td>2.8</td>
<td>0.5</td>
<td>3.1</td>
<td>0.6</td>
<td>2.8</td>
<td>0.6</td>
<td>3.0</td>
<td>0.6</td>
</tr>
<tr>
<td>AQ</td>
<td>17.9</td>
<td>5.7</td>
<td>15.7</td>
<td>6.3</td>
<td>20.7</td>
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<td>18.1</td>
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<tr>
<td>SSP</td>
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<td>18.3</td>
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<td>48.3</td>
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<td>9.0</td>
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<td>DASS</td>
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<tr>
<th>Human</th>
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<th>SD</th>
<th>Life Sci (n=249) Mean</th>
<th>SD</th>
<th>Nursing (n=57) Mean</th>
<th>SD</th>
<th>Physical and Math Sci (n=81) Mean</th>
<th>SD</th>
<th>None/Undeclared (n=152) Mean</th>
<th>SD</th>
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<td>3.0</td>
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<td>0.6</td>
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<td>0.7</td>
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<td>19.2</td>
<td>7.0</td>
<td>18.6</td>
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<td>147.8</td>
<td>18.0</td>
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<td>33.1</td>
<td>12.1</td>
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<td>9.3</td>
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Table 4

Phase 2 Participant Demographics and Behavioral Measure Mean Scores

<table>
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<tr>
<th>Cluster</th>
<th>Entire fMRI Sample (n=55) (Male = 23, Female = 32)</th>
<th>1 (n=28) (Male = 13, Female = 15)</th>
<th>2 (n=27) (Male = 10, Female = 17)</th>
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<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Age</td>
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<tr>
<td>BAPQ Total Score</td>
<td>2.9</td>
<td>0.6</td>
<td>3.3**</td>
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<tr>
<td>BAPQ Aloof</td>
<td>33.0</td>
<td>10.8</td>
<td>38.9**</td>
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<tr>
<td>BAPQ Pragmatic Language</td>
<td>34.5</td>
<td>7.4</td>
<td>38.9**</td>
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<tr>
<td>BAPQ Rigidity</td>
<td>38.2</td>
<td>8.3</td>
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<td>AQ Total Score</td>
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<td>7.3</td>
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<tr>
<td>SSP Total</td>
<td>143.5</td>
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<td>133.2**</td>
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<td>24.8**</td>
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<td>16.2</td>
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**p < .001
Figures

Figure 1

*Histogram of Participant Short Sensory Profile Total Scores With Sensory Difference Cut-Off Scores*

141-38: Definite Difference
154-142: Probable Difference
190-155: Typical Performance
Figure 2

Histograms of Participant Total Scores for Autistic Trait Measures With Cut-Off Scores

A.

B.
Figure 3

Scatter Plots of Correlations Between Measures of Sensory Processing and Autistic Traits

A. Short Sensory Profile Total Score vs. Broad Autism Phenotype Questionnaire Total Score
   \( r = -0.49; \ p < 0.001 \)

B. Short Sensory Profile Total Score vs. Autism Spectrum Quotient Total Score
   \( r = -0.41; \ p < 0.001 \)

C. Glasgow Sensory Questionnaire (GQ) vs. Broad Autism Phenotype Questionnaire Total Score
   \( r = 0.45; \ p < 0.001 \)

D. Glasgow Sensory Questionnaire (GQ) vs. Autism Spectrum Quotient Total Score
   \( r = 0.41; \ p < 0.001 \)
Figure 4

Scatter Plots of Correlations Between Measures of Sensory Processing and Psychiatric Difficulty
Figure 5

Scatter Plots of Correlations Between Measures of Sensory Processing, Autistic Traits, and Intolerance of Uncertainty
Figure 6

Comparison of Behavioral Measure Total Scores Across College Major-Based Groups
Figure 7

Comparison of Systemizing and Empathizing Quotient Total Scores Across College Major-Based Groups
Figure 8

Comparison of Behavioral Measure Total Scores in Autistic First Degree Relative Diagnosis-Based Clusters
Figure 9

Functional Network Connectivity Related to Measures of Autistic Traits and Sensory Processing

Total Scores
Figure 10

Behavioral Measure Phase 2 Participant Mean Total Scores in Connectivity-Based Clusters
Figure 11

Network Connectivity Related to Measures of Autistic Traits and Intolerance of Uncertainty

Differing Between Phase 2 Clusters
APPENDIX A

Annotated Bibliography


*Introduction:* This study aimed to determine the relationship between Intolerance of Uncertainty (IU) and anxiety in both children and adolescents with ASD and that are neurotypical. The hypothesis was that IU and anxiety would have a positive relationship in both groups of participants.

*Method:* There were 224 participants (8-18-years-old) and they were selected from two databases. Parents and children were asked to complete a set of questionnaires that included the IUS-C and IUS-P, SCAS, and Social Responsiveness Scale (SRS).

*Results:* The analyses confirmed the hypothesis that IU and anxiety have a positive relationship across groups. However, children with ASD had significantly higher levels of anxiety and IU than typically developing children. It was concluded that IU mediates the relationship between ASD diagnosis and anxiety.

*Relevance to current work:* These findings are important to the current study because they demonstrate a key relationship in both individuals with ASD and typically developing children. The current study is aiming to replicate this relationship in neurotypical young adults and add a neurobiological component.
Introduction: The purpose of this study was to examine the “diagnostic, sex-based, and compensatory differences in youth with ASD” (Corbett et al., 2021, p. 3). It was hypothesized that females would show evidence of fewer restricted and repetitive behaviors (RRB) than males and perform better at social and communication behaviors due to camouflaging or masking. This study is important for improving diagnostic criteria for females with ASD and breaking down camouflaging behaviors that are associated with high rates of self-reported anxiety.

Method: Participants (n = 161; 115 males; 46 females) were between the ages of 10:0-16:11 years old and administered a battery of tests covering diagnostic, cognitive, neuropsychological, and social communication measures. Inclusion criteria required that participants have a diagnosis of ASD according to the Diagnostic and Statistical Manual-5 (DSM-5), be verbally fluent, and have no comorbid intellectual disability.

Results: The hypotheses concerning females, RRBs, and social communication were confirmed. Because of these results, “it is likely that higher camouflaging behaviors among females with ASD may contribute to the underdiagnosis of ASD in females” (Corbett et al., 2021, p. 9).

Relevance to current work: This study supports the claim made in the current study that current diagnostic measures for ASD may be male-centric and leave females underdiagnosed. In addition, camouflaging and/or suppressing autistic traits is correlated with higher levels of anxiety which is a major construct of the current study.

**Introduction:** Abnormal sensory processing has long been established as a feature of autism in children but not adults. This study aimed to demonstrate the continuance of abnormal sensory processing across the lifespan, the heterogeneity of its presentation, and its effects on daily life.

**Method:** A total of 36 adults (18 with ASD and 18 control) participated in this study ranging from 18 to 65 years old. Participants with an ASD diagnosis were diagnosed according to the DSM-5 criteria. The WASI, AQ, and AASP were administered to each participant individually at either a common testing site or in their own homes.

**Results:** There were no significant correlations between age of the individual and level of abnormal sensory processing in either the autistic or control groups. This indicates that abnormal patterns of sensory processing do not diminish with age. A multiple case series analysis was used to examine each participant individually and demonstrated that abnormal levels of sensory processing can manifest differently (i.e., low registration, sensation seeking, sensory sensitivity, and sensation avoidance) between individuals.

**Relevance to current work:** The current study aims to replicate this study’s findings related to abnormal sensory processing and its continuance across the lifespan; therefore, supporting and validating the importance of studying the population of emerging adults.

Introduction: The aim of this study was to describe the changes in and heterogeneity of abnormal sensory processing over time in autistic and typically developing children. The typically developing group was included to demonstrate the reality of abnormal sensory processing in both groups and their overlap.

Method: Participants \(n = 115; 68\) autistic, \(47\) typically developing; initially aged 2-5 years old and aged 4-10 years old at follow-up) were recruited from UC Davis Health MIND Institute which was involved in a longitudinal project studying autistic and typically developing children. Parents of the participants filled out the Short Sensory Profile (SSP) and Childhood Behavior Checklist (CBCL) at both time intervals.

Results: Three classes of abnormal sensory processing were created: Stable Mild, Stable Intense, and Increasingly Intense. Typically developing children fell in the Stable Mild and Stable Intense classes. Participants in the Stable Intense class had extremely high levels of anxiety in addition to abnormal sensory behaviors that were also exhibited in the Increasingly Intense class. High levels of anxiety were marked at ages of transition from preschool to grade school, potentially indicating that transitional time periods provoke sensory behaviors and anxiety.

Relevance to current work: The results of this study demonstrate that abnormal sensory processing in ASD is heterogenous, is associated with anxiety, does not decrease in prevalence as age increases, and is also present in typically developing individuals. These are all points of argument in the current study. In addition, the current study is analyzing the transition from high school to college, which may present with the same pattern discovered in the transition from preschool to grade school in Dwyer et al.’s study.
Introduction: As the prevalence of ASD rises each year, there will consequently be more emerging adults with ASD. While this is the case, the research body concerning this population is relatively small compared to the literature on children with ASD. The emerging adult population (both neurotypical and with ASD) is more vulnerable to contracting psychiatric illness due to a number of life changes during this age. Studying this population is the first step to identifying necessary resources and supports for those entering college and ultimately an entirely new phase of life.

Method: This study examined the relationship between level of autistic traits and comorbid psychiatric illness in 6,146 emerging adults with ASD. Participants were recruited to join the study through an online participant research pool maintained by their university. Students were compensated with course credit for their participation and could complete the survey virtually/remotely. A digital consent form was displayed before participants could access the survey.

Results: Participants were categorized based on their levels of ASD symptoms (i.e., normal, mild, moderate, severe) and were analyzed for their co-occurring level of psychiatric symptoms. The results demonstrated that “emerging adults who presented with greater ASD symptom severity were more likely to experience the presence of additional co-morbid [psychiatric] symptoms” (Gadke et al., 2016, p. 194).

Relevance to current work: The implications for research and practice in this article directly relate to the takeaways desired for the current study—making an impact on society
of how to accommodate autistic emerging adults in college with the supports they need. The methods used are also very similar to the methods outlined for the current study.

[https://doi.org/10.1001/jamapsychiatry.2015.0737](https://doi.org/10.1001/jamapsychiatry.2015.0737)

**Introduction:** The purpose of this study was to identify the differences in “brain responses, habituation, and connectivity” (Green et al., 2015, p. 778) while listening to a mild sensory stimulus in adolescents with ASD and sensory over-responsivity (SOR), ASD and no SOR, and typically developing peers.

**Method:** Participants ($n = 19$ with ASD and 19 typically developing) were ages 9-17 years old and underwent fMRI while enduring mildly aversive tactile and/or auditory events. Parents of the participants were asked to complete the SSP and Sensory Over-Responsivity Scale regarding their child to correlate with the fMRI data.

**Results:** ASD participants had more excitation (i.e., oxygenated blood flow) in the amygdala, primary sensory areas, and orbitofrontal cortex than neurotypical controls when presented with mild auditory and tactile stimuli. This may be due to a decreased ability to neurally habituate to sensory stimuli.

**Relevance to current work:** The current study aims to replicate this study’s findings regarding the behavioral and neural relationships between abnormal sensory processing and brain areas of emotional regulation in the emerging adult population. Similar methods and analyses will also be used in the current study.
https://doi.org/10.1016/j.neubiorev.2021.04.014

**Introduction:** The neurobiological research to date concerning ASD has focused primarily on understanding the social communication mechanisms involved in the disorder. This study aims to address the neural mechanisms of sensory processing and perception in the disorder compared to neurotypical controls. This area is currently poorly understood but requires investigation as abnormal sensory processing was recently added as a key diagnostic category of ASD in the DSM-5.

**Method:** A meta-analysis was conducted of 52 fMRI studies that compared and contrasted non-social brain areas of autistic and typical individuals when engaging in non-social tasks. The first review condensed the literature to meet the criteria of the study while the second review refined studies by sensory modality (i.e., visual, auditory, tactile).

**Results:** Analyses demonstrated that autistic individuals have increased activity in primary sensory cortices (i.e., occipital, auditory, and somatosensory) and decreased activity in the frontal cortices compared to neurotypical controls.

**Relevance to current work:** The current study aims to replicate these findings via fMRI and link the neural mechanisms to their behavioral manifestations. In addition, the current study supports the notion that a sensory phenotype may serve as an early diagnostic marker for ASD in infants or children.
https://doi.org/10.1080/15248372.2016.1200046

**Introduction:** This study’s aim was to define the Broader Autism Phenotype (BAP) and provide the pros and cons of examining its prevalence in neurotypicals for the purposes of autism research.

**Summary:** The study defines the BAP as “a subclinical presentation of one or more behaviors or traits that are qualitatively similar to features of autism” (Landry & Chouinard, 2016, p. 584). The BAP can appear in family members of an autistic individual or in entirely neurotypical families. Five benefits were identified for using the BAP as a model for understanding ASD. First, the BAP can be measured in neurotypical individuals which allows for easier access to greater sample sizes, a wider range of variability, and more statistically powerful analyses. Second, studying neurotypicals removes the potential study limitations set by using persons with ASD like testing session length, amount of sensory stimuli, cognitive load, etc. Third, studying typically developing individuals allows for more control of comorbid disorders. Fourth, it allows for control of both chronological and mental age and makes matching a control group simpler. Fifth, using the BAP “provides the opportunity to examine the developmental sequence and correlates of skills implicated in ASD in greater isolation” (Landry & Chouinard, 2016, p. 589).

**Conclusions:** Using the BAP model to study typically developing individuals for autism research will more easily and quickly help uncover answers to questions about ASD including variations, neurophysiologic differences, and developmental trajectories.
Relevance to current work: This paper supports the use of the BAP model to study neurotypical individuals for autism research which is a major focus of and framework for the current study.

[https://doi.org/10.1080/07448481.2018.1440576](https://doi.org/10.1080/07448481.2018.1440576)

Introduction: The purpose of this study was to examine the relationship between autistic traits in emerging adulthood and parenting style (i.e., parental distress, conflict strategies) and their effects on the parent-child relationship from the viewpoint of emerging adults.

Method: Study participants (*n* = 6,146; 18-25 years old) were university students recruited using an online research pool called SONA Systems. Participants volunteered for the study after reading a study description and indicating consent. They also received course credit for their participation. Participants completed a list of surveys at random including the ASR, ABCL, PAQ, PEQ, and CTSPC.

Results: The study concluded that autistic traits in emerging adults have a strong relationship with parenting characteristics (i.e., higher levels of autistic traits were associated with perceived larger levels of ineffective parenting exercises).

Relevance to current work: The implications for clinical practice and future research from this study are what directly relate to the current work. First, there is an immense need for literature addressing assessment, treatment, and symptoms of ASD in adulthood. Second, despite good psychometrics properties, the available surveys for assessing ASD in adulthood are limited and without a history of research validation. Finally, the participant and recruitment parameters are very similar to the current study.

*Introduction:* The purpose of this study was to demonstrate the link between autistic traits and sensory sensitivity in the general population. The hypothesis was that participants who scored “high” on the measure of autistic traits would also score “high” on a sensory questionnaire. This information would be important for understanding sensory processing’s impact on social interaction difficulties—a hallmark trait of ASD.

*Method:* The researchers used two self-reported questionnaires to gather information—the Glasgow Sensory Questionnaire (GSQ; which was developed by the authors) and the Autism Quotient (AQ). Participants (n = 212) were an average of 26.75 years old and were recruited from the general population via email chaining, word-of-mouth, and online forums.

*Results:* A positive, linear relationship was found between total sensory scores and AQ scores (r = .775), demonstrating that high levels of autistic traits are positively correlated with abnormal levels of sensory sensitivity.

*Relevance to current work:* The current study is also using the general population to analyze the relationship between autistic traits and sensory processing, but is doing so behaviorally and neurologically. Both studies share participant methodology, hypotheses, and the importance of publicizing this correlation in the general population.

Introduction: Abnormal sensory processing, alexithymia (i.e., impairments in emotion understanding and identification), and IU all appear to be associated in predicting anxiety in autistic individuals. This mini-review article aimed to further explore the relationship between these factors and other related neural networks (i.e., medial prefrontal cortex, limbic system, and insula-based networks).

Summary: Anxiety was discovered to be more severe in autistic individuals with severe abnormal sensory processing. This relationship was found to be mediated by a combination of alexithymia, IU, and emotional acceptance. In addition, IU and anxiety were revealed to mediate the relationship between abnormal sensory processing and autistic traits (i.e., RRBs). The medial prefrontal cortex (mPFC) appears to have decreased input to the amygdala in individuals with ASD which results in decreased modulation of social stimuli and emotional response. These dysfunctions then result in anxiety.

Conclusions: The research confirms that abnormal sensory processing, alexithymia, and IU predict later-emerging anxiety in autistic individuals. The neural networks involved in this relationship require further investigation in order to lead to better intervention for anxiety and IU in ASD.

Relevance to current work: The current study is also investigating the relationship between abnormal sensory processing, anxiety, impaired emotional regulation, and IU in autistic individuals. fMRI will be used to examine the same neural correlates explored in this article.


https://doaj.org/article/68c070dceefb40da9bc201f99506dcdh
Introduction: Emerging adulthood is a highly transitional period of life that presents many challenges, decisions, responsibilities, and roles. The core characteristics of ASD may make this period of life difficult for those with a diagnosis. As a result, this study “aimed to explore the relationships between sensory over-responsivity, problem behaviors, and anxiety in emerging adults with ASD” (Syu et al., 2020, p. 2183). The anxiety experienced by these individuals could be due to the changing social and physical environments associated with this age.

Method: Participants (n = 57) were between the ages of 18 and 25 and had a diagnosis of ASD according to the DSM-5. They were recruited through Facebook, foundations or associations for ASD, resource classrooms at universities, and hospitals. Participants were administered a series of questionnaires physically and/or electronically.

Results: It was reported that sensory over-responsivity significantly correlated with problem behaviors and that anxiety was a mediating variable between these two factors. In addition, more than 64% of autistic individuals in the study scored on or above the cut-off of six on the Generalized Anxiety Disorder-7 (GAD-7).

Relevance to current work: This study demonstrates the importance of examining the emerging adult population of autistic individuals and that psychiatric illness is positively correlated with abnormal levels of sensory processing.


Introduction: This study evaluated the manifestation of sensory symptoms in children with ASD and their relationship to empathizing and systemizing cognitive abilities. These
children were compared to children with sensory processing disorder (SPD) and typically developing children to see if there were distinct differences within these relationships between the groups of children.

Method: The study recruited 210 participants (68 with ASD, 79 with SPD, 63 typically developing) ranging from 5-15 years old. Their parents were asked to complete an online test consisting of the AQ-Child, the Sensory Processing Scale (SP), the EQ, and the SQ.

Results: Across all groups, higher levels of empathy were associated with fewer sensory symptoms. In the children with ASD, there were generally low empathizing skills and high systemizing skills. In addition, they had the most sensory abnormalities. Greater levels of autistic traits were associated with more abnormal sensory processing in the SPD and typically developing groups.

Relevance to current work: This study demonstrated that abnormal sensory processing influences an autistic individual’s ability to empathize, and therefore participate fully in social interactions. The current study is interested in sensory processing and its relationship to systemizing and empathizing and how that impacts the lives of individuals with ASD.


Introduction: This study is an attempt to report the most significant findings and major trends discovered in autism research over the past decade. Definitions, diagnosis, assessment measures, epidemiology, models, brain mechanisms, genetics, treatments, and future implications are covered.
**Summary:** Functional MRI (fMRI) was deemed an appropriate neuroimaging technique for studying neural networks that “underlie the cognitive, behavioral, and social-emotional” difficulties that define ASD (Volkmar et al., 2004, p. 145). The brain areas/systems currently under speculation include the limbic system (i.e., amygdala and hippocampus), medial temporal lobe, cerebellum, areas involved in the ‘social brain’ (i.e., orbital and medial prefrontal cortices, superior temporal sulci), and the fusiform face area (FFA).

**Conclusions:** fMRI can be used to identify specific aberrant brain functions or neural networks in autistic individuals by comparing their fMRI data to data from neurotypical individuals.

**Relevance to current work:** The current study is interested in analyzing the neurobiological underpinnings of autistic traits, sensory processing, and other related behaviors in neurotypical individuals. Volkmar et al. (2004) identified a successful neuroimaging technique for comparing autistic and neurotypical individuals and several brain areas of interest to the current study.


**Introduction:** Reliably and consistently diagnosing ASD in adulthood is currently a challenge in the medical world. The purpose of this study was to systematically review the psychometric properties of structured questionnaires and diagnostic measures that assess ASD in adults. In addition, the researchers made recommendations for the most appropriate diagnostic measures based on the current evidence.
**Method:** Papers were found through the National Institute for Health and Care Excellence (NICE) database and coincided with the revised criteria for ASD as established in the DSM-5. Titles and abstracts were screened, with 20% of articles screened by a second reviewer that resulted in 96% inter-rater reliability.

**Results:** Twenty articles were included in the systematic review. The structured questionnaires, diagnostic measures, and observational assessments that were evaluated in the studies and included in the review consisted of the AQ, RAADS-R, SRS-2, SCQ, SCQ-AID, DiBAS-R, ACL, ADI-R, ADOS-G, and AMSE. The review found that “overall, there is very limited evidence to support the use of [structured questionnaires] in the assessment and diagnosis of ASD in adults” (Wigham et al., 2019, p. 300). Likewise, the use of diagnostic measures (including the ADOS-G) suggested “some utility in identifying ASD among clinic referrals, although specificity for eventual diagnosis of ASD was still relatively low” (Wigham et al., 2019, p. 300). Overall, it should be noted that these tools are useful but only to aid “diagnostic decision-making within a broader multidisciplinary team ASD assessment” (Wigham et al., 2019, p. 301).

**Relevance to current work:** This study is relevant because the current work is supporting the statement that ASD diagnosis in adulthood is complex. In addition, the current study is investigating potential neurophysiologic diagnostic measures of ASD.


**Introduction:** This study’s purpose was to identify relationships between abnormal sensory processing, RRBs, anxiety, and intolerance of uncertainty (IU) in individuals with ASD. It
was hypothesized that sensory over-responsivity would result in IU and anxiety and that sensory under-responsivity would result in RRBs without anxiety or IU.

Method: Participants \((n = 53; \text{8-16 years old})\) were recruited from two ASD databases and all had clinical diagnoses of ASD. Their parents were asked to complete a battery of surveys. This included the SSP, Spence Children’s Anxiety Scale (SCAS), IUS-P, and the Repetitive Behavior Questionnaire (RBQ).

Results: Anxiety, IU, and RRB were significantly correlated with greater sensory over-responsivity. Sensory under-responsivity was not associated with anxiety or IU but was significantly negatively correlated with RRBs and insistence on sameness. Overall, IU was found to be the mediating variable between sensory processing and anxiety in ASD.

Relevance to current work: The current study aims to demonstrate the association between sensory processing, anxiety, and IU both behaviorally and neurobiologically. This study supports the behavioral relationship between these factors.
APPENDIX B

Consent/Institutional Review Board Approval Letter

Memorandum

To: Garrett Cardon

Department: BYU - EDUC - Communications

Disorders From: Sandee Aina, MPA, HRPP

Associate Director

Wayne Larsen, MAcc, IRB

Administrator Bob Ridge, Ph.D., IRB Chair

Date: December 01, 2020

IRB#: IRB2020-473

Title: Sensory Abnormalities and Autistic Traits: Behavioral and Neural Correlates

Brigham Young University’s IRB has approved the research study referenced in the subject heading as expedited level, categories 4 and 7. The approval period is from 12/01/2020 to 11/30/2021. Please reference your assigned IRB identification number in any correspondence with the IRB. Continued approval is conditional upon your compliance with the following requirements:
1. A copy of the approved informed consent statement and associated recruiting documents (if applicable) can be accessed in iRIS. No other consent statement should be used. Each research subject must be provided with a copy or a way to access the consent statement.

2. Any modifications to the approved protocol must be submitted, reviewed, and approved by the IRB before modifications are incorporated in the study.

3. All recruiting tools must be submitted and approved by the IRB prior to use.

4. In addition, serious adverse events must be reported to the IRB immediately, with a written report by the PI within 24 hours of the PI's becoming aware of the event. Serious adverse events are (1) death of a research participant; or (2) serious injury to a research participant.

5. All other non-serious unanticipated problems should be reported to the IRB within 2 weeks of the first awareness of the problem by the PI. Prompt reporting is important, as unanticipated problems often require some modification of study procedures, protocols, and/or informed consent processes. Such modifications require the review and approval of the IRB.

6. A few months before the expiration date, you will receive a prompt from iRIS to renew this protocol. There will be two reminders. Please complete the form in a timely manner to ensure that there is no lapse in the study approval. Please refer to the IRB website for more information.

Instructions to access approved documents, submit modifications, report complaints, and adverse events can be found on the IRB website under iRIS guidance: https://irb.byu.edu/iris-training-resources.
Phase 1 Consent Form

You are being invited to participate in a research study of the brain mechanisms underlying social functioning in young adults.

Your participation in this study will require the completion of the attached survey. This should take between 30-60 minutes of your time. Your participation will be anonymous, and you will not be contacted again in the future, unless you wish to participate in future phases of the study. If you complete the survey, you will be entered into a drawing for one of four $50 gift cards. This survey involves minimal risk to you. The benefits, however, may impact society by helping increase knowledge about real-world and brain-based aspects of social function and related behaviors in people between the ages of 18-25.

You will be asked at the end of the survey if you’d like to participate in future phases of the study, at which time you’ll be provided a place to enter your contact information. Participants who qualify for phase 2 of the study will be asked to undergo a non-invasive brain scan (MRI) and compensated for their participation.

You do not have to be in this study, if you do not desire. We will be happy to answer any questions you have about this study. If you have further questions about this project or if you have a research-related problem you may contact our Research Coordinator, at BYUsocialstudy@gmail.com or Principal Investigator, Garrett Cardon, at garrett.cardon@byu.edu.

If you have any questions about your rights as a research participant you may contact the IRB Administrator at A-285 ASB, Brigham Young University, Provo, UT 84602; irb@byu.edu; (801) 422-1461. The IRB is a group of people who review research studies to protect the rights and welfare of research participants.

The completion of this survey implies your consent to participate. If you choose to participate, please complete the attached survey. Thank you!
You are being asked to be in a research study. This form provides you with information about the study. A member of the research team will describe this study to you and answer all of your questions. Please read the information below and ask questions about anything you don’t understand before deciding whether to take part.

**Why is this study being done?**
You are being asked to participate in a research study of differences in brain anatomy and function in young adults, related to their social interaction styles. We believe that social interaction styles are related to sensory processing, anxiety, and peoples’ ability to empathize with others. We are trying to discover the mechanisms for this difference by studying the relevant areas of the brain. You have been asked to take part in this research study because you are a young adult between the ages of 17-26.

**Other people in this study?**
Up to 100 people from your area will participate in the study.

**What happens if I join this study?**
If you join the study, you will participate in a Magnetic Resonance Image (MRI) of your brain at the BYU MRI facility. MRI is a technique that uses a magnetic field and radiofrequency energy to obtain pictures of parts of the human body. You will be interviewed before the scan to be certain that you do not have implanted metallic devices such as a pacemaker or metallic clip of a blood vessel in your brain. During the scan, you will lie down on a padded table which will be moved into a large cylinder. You will need to lie very still while the MRI scan is performed. You will not feel anything during the scan but will hear loud noises made by the scanner as the pictures are taken.

*Note:* In this case, MRI is an experimental procedure and therefore, has no clinical interpretation.

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What are the possible discomforts or risks?
There are no known significant risks involved in this research study. Some people become
claustrophobic during the MRI procedure. You may become tired during the MRI recording and
will be given rest breaks, as needed. There are no known risks for exposure to the types of
magnetic fields and radio waves which are used in MRI, but there is always a possibility a small,
unknown risk may exist to this or any test. Rarely (one in thousands of exams), a sunburn-like
skin burn may occur over a small area of the body during the MRI. We take special precautions
for this not to occur. However, we believe that we have taken reasonable precautions to ensure
your safety. If you have any questions about your safety in this experiment, please feel free to
discuss them with us at any time. There is a risk that people outside of the research team will see
your research information. We will do all that we can to protect your information, but it cannot be
guaranteed.

What are the possible benefits of the study?
This study is designed for the researcher to learn more about the social interaction styles of
young adults. This study is not designed to treat any illness or to improve your health. We will
not release any clinically un-interpretable results. Also, there are risks as mentioned in the
Discomforts and Risks Section above.

Who is paying for this study?
The sponsor for this study is the National Institute of Health and Brigham Young University.

Will I be paid for being in the study?
You will be paid $10 per hour for participation in this study at the end of each day. If either you
or research personnel decide to withdraw yourself from the study, you will still receive the
hourly rate for all your participation up to the point when you withdraw.

Will I have to pay for anything?
There is no cost to you for participating in this study. There will be no charge for procedures
required by the study.

Is my participation voluntary?
Taking part in this study is voluntary. You have the right to choose not to take part in this study.
If you choose to take part, you have the right to stop at any time. If there are any new findings
during the study that may affect whether you want to continue to take part, you will be told about
them.

Can I be removed from this study?
The research team may decide to stop your participation without your permission, if they think
that being in the study may cause you harm, or for any other reason. We will pay for the hours
you have been in the research study up to the time you withdraw from the research study. Some of
the other reasons for stopping your participation include having non-removable metallic implants
in your body that are found to be magnetic. Also, the sponsor may stop the study at any time.

What happens if I am injured or hurt during the study?
You should inform your care provider(s) if you decide to participate in this research study. If you
have an injury while you are in this study, you should call Garrett Cardon at (303) 241-6666
and/or your private physician. We will arrange to get you medical care if you have an injury that
is caused by this research. However, you or your insurance company will have to pay for that care.

**Who do I call if I have questions?**
The researcher carrying out this study is Garrett Cardon, Ph.D. You may ask any questions you have now. If you have questions later, you may call Dr. Cardon at (303) 241-6666. You will be given a copy of this form to keep.
You may have questions about your rights as someone in this study. You can call Dr. Cardon with questions. You can also call the responsible Institutional Review Board (BYUIRB). You can call them at (801) 422-3841.

**Who will see my research information?**
Brigham Young University and the research team have rules to protect information about you. Federal and state laws including the Health Insurance Portability and Accountability Act (HIPAA) also protect your privacy. This part of the consent form tells you what information about you may be collected in this study and who might see or use it.
The institutions involved in this study include Brigham Young University
We cannot do this study without your permission to see, use and give out your information. You do not have to give us this permission. If you do not, then you may not join this study.
We will see, use, and disclose your information only as described in this form. We will do everything we can to keep your records a secret. It cannot be guaranteed.
The use and disclosure of your information has no time limit. You can cancel your permission to use and disclose your information at any time by writing to the study’s Primary Investigator, at the name and address listed below. If you do cancel your permission to use and disclose your information, your part in this study will end and no further information about you will be collected. Your cancellation would not affect information already collected in this study.

Garret Cardon  
Brigham Young University  
Department of Communication Disorders  
1190 N 900 E 130 TLRB  
Provo, UT 84604

Both the research records that identify you and the consent form signed by you may be looked at by others who have a legal right to see that information.

- Federal offices such as the Food and Drug Administration (FDA) that protect research subjects like you.
- People at the Brigham Young University Institutional Review Board (BYUIRB)
- The study investigator and the rest of the study team.
- NIH, who is one of the organizations paying for this research study.
• Officials at the institution where the research is being conducted and officials at other institutions involved in this study who oversee making sure that we follow all the rules for research.

We might talk about this research study at meetings. We might also print the results of this research study in relevant journals. However, in either of these cases, we will always keep the names and other identifying information of the research subjects, like you, private.

**Information about you that will be seen, collected, used, and disclosed in this study:**
- Name and Demographic Information (age, sex, ethnicity, address, phone number, etc.)
- Research Visit and Research Test records
- Diagnoses that have been given to you or your close family members, such as anxiety, Autism Spectrum Disorder (ASD), or Attention Deficit Hyperactivity Disorder (ADHD)

**What happens to data that is collected in this study?**
The scientists on the research team work to find the causes and cures of disease. The data collected from you during this study is important to this study and to future research. If you join this study:
- Both the investigators and any sponsor of this research may study your data
- Any product or idea created by the researchers working on this study will not belong to you.
- There is no plan for you to receive any financial benefit from the creation, use or sale of such a product or idea.

**HIPAA Authorization for Optional Additional Study Procedures**
In this form, you were given the option to agree to additional, optional research procedures. You must also give us your permission, under HIPAA rules, to use and disclose the information collected from these optional procedures, as described above. These optional procedures involve genetic testing or the use of your genetic information. Your genetic information will be released to your health care practitioner if you so choose.

If you decline to give us permission to use and disclose your information, you cannot take part in these optional procedures, but you can still.
Agreement to be in this study and use my data
I have read this paper about the study, or it was read to me. I understand the possible risks and benefits of this study. I understand and authorize the access, use and disclosure of my information as stated in this form. I know that being in this study is voluntary. I choose to be in this study: I will get a signed and dated copy of this consent form.

Signature:

Date:

Print Name:

Consent form explained by:

Date:

Print Name:

PERMISSION TO CONTACT FOR FUTURE RESEARCH STUDIES: Sometimes after a research project is finished, there are new questions that researchers need to ask and new research studies that need to be done. We would like your permission to contact you for participation in future studies that you/your child may qualify for. We will not contact you unless you give us your permission.

_____ I agree to be contacted for future research studies that I/my children might be eligible for.

_____ I do not wish to be contacted in the future for any additional research studies.

If you agree to be contacted, please list an address, phone number, and email address where you can be reached:

Phone:______________________________________________________________

Email:
## APPENDIX C

### Supplementary Data

Functional Connectivity in Independent Components

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