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# EXAMINING OROFACIAL SOMATOSENSATION DIFFERENCES IN ADULTS WITH AND WITHOUT ADHD

A Thesis in

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by

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## ABSTRACT

Individuals with attention-deficit/hyperactivity disorder (ADHD) have reported secondary symptoms such as speech problems, somatosensory impairments, and sensory processing deficits. Current research efforts to assess these symptoms have focused on children with ADHD. The purpose of this study was to investigate the relationship of these secondary symptoms in adults with ADHD compared to age-matched controls. Twenty adults with ADHD and 20 age-matched adults without ADHD were recruited for this study. All participants provided a speech sample, completed bilateral lip and tongue somatosensory assessments, and completed the Adult/Adolescent Sensory Profile (AASP). Differences between groups were assessed using independent t-tests. Although individuals with ADHD demonstrated increased reading time, decreased reading accuracy, and decreased tactile detection and discrimination abilities; none reached the level of significance. Adults with ADHD reported significantly more sensory under- and over-responsivity behaviors. Correlational analyses were used to assess the relationship between reading time and accuracy, 2-pt discrimination, tactile detection and discrimination, and prevalence of sensory under- and over-responsivity behaviors in adults with ADHD. Decreased two-point discrimination abilities in left tongue and right lip were correlated with the speech measures: passage time ($r$ (40) = 0.333, p = .036) and passage errors made ($r$ (40) = -0.317, p = .046), respectively. Sensory over-responsivity was correlated with two of the somatosensory measures: tactile detection left tongue ($r$ (37) = 0.341, p = .039) and tactile discrimination right tongue ($r$ (37) = 0.341, p = .039). These results suggest adults with ADHD over respond to stimuli as a result of decreased sensitivity.

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## Acknowledgments

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# Chapter 1: Introduction

Attention-deficit/hyperactivity disorder (ADHD) is the predominant neurobehavioral disorder of childhood whose symptoms often continue into adulthood (Barkley & Murphy, 2006; Efron, Hazell, & Anderson, 2011). ADHD is traditionally characterized by long-lasting symptoms of inattention, hyperactivity and impulsivity; however, research has also suggested the presence of deficits in other realms, such as timing (Valera, et al., 2010), motor control (Barkley, 1998), somatosensation (Duerden, Tannock, & Dockstader, 2012; Parush, Sohmer, Steinberg, & Kaitz, 1997) and sensory perceptual processing in individuals with ADHD (Broring, Lambregts-Rommelse, Sergeant, & Scherder, 2008; Ghanizadeh, 2011; Micoulaud-Franchi, et al., 2015). Additionally, individuals with ADHD frequently have a comorbidity of speech and language disorders characterized by an increased number of disfluencies (Engelhardt, Corley, Nigg, & Ferreira, 2010), poor auditory comprehension (McInnes, Humphries, Hogg-Johnson, & Tannock, 2003), pragmatic difficulties (Bishop & Baird, 2001; Cohen, et al., 2000; Geurts & Embrechts, 2008), and poor articulation (Iwanaga, Ozawa, Kawasaki, & Tsuchida, 2006).

To the best of our knowledge, there is no research that examines the interaction between somatosensation and speech in individuals with ADHD. Oral somatosensation is paramount for skilled activities of daily living, such as speech and swallowing (Kort, Cuesta, Houde, & Nagarajan, 2016; Simmonds, Leech, Collins, Redjep, & Wise, 2014). It is imperative oral tactile sensation remains intact as speech is a highly coordinated and precise function. For example, the presence or absence of awareness of light touch from our articulators, such as the lip or tongue, can result in imprecise consonant production (Casserly, Rowley, Marino, & Pollack, 2017).

Dunn’s Model of Sensory Processing reflects a relationship between neurology and behavior (Dunn, 1997). Dunn describes neurologic thresholds as the level of incoming sensory stimuli needed for detection by the nervous system (Dunn, 1997). Consequent behaviors reflect how an individual responds to those neurologic thresholds (Dunn, 1997). The interactions between neurological and behavioral continuums result in individual sensory preferences. When these sensory preferences begin to impact our lives in a negative fashion, we must start to treat them as a dysfunction (Clince, Connolly, & Nolan, 2016). Previous research has shown individuals with ADHD have different sensory preferences, particularly slowed responses to incoming stimuli, compared to those without ADHD (Clince, et al., 2016; Gutman & Szczepanski, 2005). Sensory Processing Disorder (SPD) is a classification system created by Miller, Anzalone, Lane, Cermak, and Osten (2007). Researchers studying SPD suggest three classes to describe altered behavioral responses to incoming sensory stimuli, which are: (1) sensory modulation disorder (sensory over-responsivity, sensory under-responsivity, and sensory seeking), (2) sensory based motor disorder (dyspraxia and postural disorder) and (3) sensory discrimination disorder (Miller, et al., 2007). In studies conducted primarily within children with ADHD, researchers found evidence of both sensory under-responsivity and over-responsivity (Mangeot, et al., 2001). Sensory under-responsivity results in responses to incoming stimuli that are delayed or absent, whereas sensory over-responsivity results in responses that are quicker, prolonged or more intense. A systematic review (up to January 2010) on sensory processing problems in children with ADHD found only 11 studies, which used questionnaires and/or parent report (for review, see Ghanizadeh, 2011). Parush, Sohmer, Steinberg, and Kaitz (2007) found tactile defensiveness or over-sensitivity to be an impairment of the processing of somatosensory information. Additional research has provided evidence of impaired sensory processing in adults as well (Dockstader, et al., 2008; Stevens, et al., 2012), which can result in slow reaction times (Cross-Villasana, et al., 2015) and decreased pain thresholds in adults with ADHD (Treister, Eisenberg, Demeter, & Pud, 2015).

The evidence of altered somatosensation (Duerden, et al, 2012; Parush, et al, 1997) and speech problems (Engelhardt, et al., 2010; Iwanaga, et al., 2006) in individuals with ADHD allows us to pose the question of whether individuals have decreased oral somatosensation, which consequently affects their speaking ability. Moreover, is there a pattern to how they respond to incoming oral somatosensation stimuli? Perhaps if individuals tend to under-respond to tactile sensory stimuli, then the articulators may not have access to accurate sensory information, which can result in slurred speech. On the other hand, one can pose the question that if individuals over-respond to tactile sensory stimuli, then the individual may speak more quickly or produce more disfluencies. In either case, impacted oral somatosensation could result in altered speech intelligibility. Somatosensation is often assessed using Semmes-Weinstein monofilaments, also called von Frey hair monofilaments, and by using two-point discrimination. The current study seeks to use these quantitative somatosensory tools to assess oral somatosensation and to look for any associations between oral somatosensation and the collected speech samples. Outcomes on the sensory measures can provide information on whether oral somatosensation is altered within this population and whether adults with ADHD tend to respond in a consistent manner to incoming stimuli. Outcomes on the speech measures will allow us to see if having low or high oral somatosensation results in faster reading or more erred speech productions.

# Chapter 2: Literature Review

## Sensation Overview

The five basic sensory systems are visual, auditory, olfactory, taste, and somatosensation. Sensory perception allows us to experience the external world around us using sensory receptors. The five types of sensory receptors are chemoreceptors (chemical), nociceptors (pain), mechanoreceptors (physical), thermoreceptors (temperature), and photoreceptors (light). Touch sensation (or somatosensation) and taste sensory systems are the most prominent systems within the oral cavity (Jacobs, et al., 2002). The predominant receptors for oral somatosensation are nociceptors, mechanoreceptors, and thermoreceptors (Jacobs, et al., 2002; Haggard & de Boer, 2014). These receptors send afferent signals to the thalamus via the trigeminal nerve (Cranial Nerve V), which is considered to be a mixed cranial nerve as it has both sensory and motor fibers (Haggard & de Boer, 2014). After the thalamus, the sensory signal is then sent to the primary somatosensory cortex. The sensory nerve endings of the trigeminal nerve innervate the orofacial region, including the lips and tongue (Haggard & de Boer, 2014; Waite & Ashwell, 2004).

**Mechanoreceptors.** A receptive field refers to the space surrounding a sensory receptor. In regards to orofacial somatosensation, it is the cutaneous area surrounding a mechanoreceptor, which can differ in size. Type I receptors are small and clearly defined where type II are large and not as defined. Small receptive fields such as those present in lips and fingers allow humans to interpret sensory information to a fine degree. Areas such as arms and thighs have much larger receptive fields. Mechanoreceptors deliver information about physical stimuli, which includes touch and pressure, and exist within multiple structures of the mouth, such as the lip and tongue (Haggard & de Boer, 2014). Cutaneous mechanoreceptors can be classified in two ways. One way is by the type of sensation they perceive, and by the speed in which they adapt. The four cutaneous mechanoreceptors, Merkel, Ruffing, Meissner, and Pacinian corpuscles, exist in glabrous or non-hairy skin (Bolanowski, Gescheider, Verillo, & Checkosky, 1988); however, only three of the four (Merkel, Ruffini, and Meissner) exist in the orofacial region (Trulsson & Johansson, 2002). Each receptor type responds differently to inputs. Merkel and Ruffini mechanoreceptors are slowly adapting (corpuscles) and the Meissner corpuscle is rapidly adapting (Trulsson & Johansson, 2002). Slowly adapting (Type I) mechanoreceptors have a consistent response to a constant physical stimulus; they respond while the stimulus is present. Rapidly adapting (Type II) mechanoreceptors have a response only when the stimulus is first presented or removed; meaning that they are good at detecting on/off moments. The surface of the tongue contains mostly rapidly adapting mechanoreceptors (Haggard & de Boer, 2014). The anterior portion of the tongue is considered to have higher sensitivity than the posterior portion due to a large density of mechanoreceptors (Trulsson & Essick, 1997; Trulsson & Johansson, 2002). The lips contain both slowly and rapidly adapting mechanoreceptors and are also considered to have high sensitivity due to the large mechanoreceptive density (Trulsson & Johansson, 2002).

**Somatosensory transduction.** The trigeminal nerve innervates the orofacial area and is responsible for transmitting somatosensory/touch information from the face. Incoming orofacial somatosensory stimuli get transferred centrally via the trigeminal nerve to the thalamus (responsible for relaying sensory and motor signals). From the thalamus, the sensory signal information is sent to the cortical area in the primary somatosensory cortex (S1) associated with orofacial sensation (Jacobs, et al., 2002). Mapping of the primary sensory cortex highlights the proportions of the brain responsible for sensory function processing for all cutaneous mechanoreceptors of the body. Interestingly, the space designated to a specific body location on

S1 does not reflect physical size of that body part. Instead, space on S1 reflects the concentration of somatosensory receptors within that specific body region (Linkenauger, et al., 2015). The concentration level of mechanoreceptors reflects the level of sensitivity towards touch stimulation experienced by an area. The orofacial region of the body occupies more space than other body regions, suggesting the possibility of increased sensitivity to touch information (Linkenauger, et al., 2015)). Identification of lip and tongue somatosensation is important for functional activities since they play a role in daily activities, including speech and swallowing (Hihara, et al., 2017).

The learning experiences during infancy often serve as the foundation for later acquired skills. Somatosensation is one of the earliest sensory systems to develop (Cascio, 2010; Montagu, 1986) and is instrumental in motor, social, and communication development (Cascio, 2010). Intact somatosensory functioning is the foundation for high-quality sensory processing, which refers to the complete course of receiving, interpreting, and responding to sensory information coming from one's body that includes tactile and kinesthetic information (Scherder, Rommelse, Broring, Faraone, & Sergeant, 2008). Difficulties in tactile perception can contribute to fine motor difficulties in skills like handwriting and speech, which one study has concluded to be a result of decreased sensory feedback (Gillberg, 2014).

**Sensory Processing**

Sensory processing is a term used within the clinical and research realms referring to the ability to take in afferent information and coordinate appropriate motor responses. The term 'sensory processing disorder,' or SPD, has been used to define when there are impairments in the body's ability to carry out this activity. Although recognized in the Diagnostic Classification of Mental Health and Developmental Disorders of Infancy and Early Childhood-Revised (known as the DC: 0-3R) (Zero to Three, 2005) and the Diagnostic Manual for Infancy and Early Childhood of the Interdisciplinary Council on Developmental and Learning Disorders (ICDL, 2005), SPD has not been adopted by the Diagnostic and Statistical Manual of Mental Disorders, 5th Edition (known as the DSM-V). It has not been included in the DSM-V due to uncertainty that those experiencing sensory processing difficulties have "an actual disorder of the sensory pathways of the brain or whether these deficits represent differences associated with other developmental and behavioral disorders" (American Academy of Pediatrics [AAP], 2012). As a result, a call for more research has been made by the DSM-V committee to produce evidence regarding this classification prior to officially recognizing SPD (AAP, 2012). For the purposes of this paper, SPD will be considered a theoretical framework as opposed to a clinical diagnosis. Miller and colleagues (2007) suggested a classification for sensory processing disorder (SPD) in which the three categories and their subtypes were defined as:

- Sensory Modulation Disorder (SMD), including sensory over-responsivity, sensory under-responsivity, and sensory seeking;
- Sensory-Based Motor Disorder (SBMD), including dyspraxia and postural disorder; and
- Sensory Discrimination Disorder (SDD).

SMD indicates a deficit in the ability to prepare a behavioral response that matches the level of the message obtained from the sensory information; SBMD is the manifestation of a breakdown within one's proprioceptive and vestibular senses; and SDD occurs when there is an impairment differentiating between similar sensations in one or more system (Miller & Fuller, 2006, p. 12). As mentioned earlier, SMD can result in sensory over-responsivity, sensory under-responsivity, or sensory seeking. Clince et al. (2016) reported individuals with sensory over-responsivity react to sensation quicker or for longer periods, those with sensory under-responsivity either do not react or react slowly, and those who are sensory seeking search for specific types of sensation or crave large amounts of sensory stimulation. Under the SPD pattern of SBMD, one would experience difficulty with movement sequences falling within the subtype of dyspraxia or postural disorder. Individuals with dyspraxia can have trouble with gross, fine-motor, oral-motor, or any combination of these movements system (Miller & Fuller, 2006, p. 32). Last, but not least, individuals with SDD when compared to typically developing children may require extended time on tasks because they are experiencing a difficult time perceiving incoming sensory stimuli from any of the sensory systems (visual, auditory, tactile, taste, smell, balance and proprioception) (Miller & Fuller, 2006, p. 37).

SPD evolved from Ayres' theory of sensory integration. Ayres defined sensory integration as "the neurological process that organizes sensation from one's own body and from the environment and makes it possible to use the body effectively within the environment" (Ayres, 1972, p. 11). The three claims of her theory are (a) the ability to learn is reliant on the effective perception and interpretation of sensation and responding appropriately; (b) learning and behavior can be subsequently affected if this ability is reduced; and (c) improved learning and behavior can come from sensation that is heightened within a functional activity as it will improve processing (Bundy, Lane, & Murray, 2002, p. 5). Sensory processing has been shown to be affected within various populations, including those with ADHD. Assessment of sensory deficits in individuals with ADHD can support differential diagnosis and direct treatment efforts.

**Adolescent/Adult Sensory Profile (AASP)**

The AASP has been used in populations, such as autism and ADHD, because individuals in these groups present with higher amounts of sensory behavioral responses as compared to the general population (Dunn, 1997). The AASP is a self-questionnaire created by Brown and Dunn based on the Sensory Profile (Dunn, 1999), which was developed for children aged 3-10 years. It is used to measure sensory processing, which in turn provides information regarding one's sensory preferences. Dunn's Model of Sensory Processing (1997) provides the conceptual framework for the AASP. The model suggests a continuous interaction between neurological thresholds and behavioral responses. The neurological threshold describes the amount of sensory stimuli needed to get the nervous system to respond and it ranges from low to high. The term 'behavioral responses' describes the manner in which individuals react to sensory stimuli and it ranges from passive to active. The interaction between the neurological threshold and behavioral response create four categories or quadrants; these quadrants are: low registration, sensation seeking, sensory sensitivity, and sensation avoiding (Dunn, 1997).

Individuals who fall under the quadrant <u>low registration</u> tend to under-respond to stimuli, so they require intense or large amounts of stimuli to become engaged. This aligns with sensory under-responsivity within the SMD category of SPD proposed by Miller et al. (2007) (Clince, et al., 2016). Individuals who are under the quadrant of <u>sensation seeking</u> have high neurologic thresholds meaning they require large amounts of stimuli to become engaged, but they will produce behaviors (e.g., moving constantly, touching excessively) to obtain additional sensation. This aligns with sensory seeking within the SMD category of SPD (Clince, et al., 2016). Those who fall within the <u>sensory sensitivity</u> quadrant have a low neurological threshold and require minimal amounts of incoming sensory stimuli, but are also hyperaware of each incoming stimulus. Individuals falling in the <u>sensation avoiding</u> quadrant have low thresholds and will minimize their exposure to incoming stimuli. Both of these quadrants, sensory sensitivity and sensation avoiding, align with sensory over-responsivity within the SMD category of SPD proposed by Miller et al. (2007) (Clince, et al., 2016).

**Attention Deficit Hyperactivity Disorder (ADHD)**

ADHD is most commonly diagnosed in childhood, and persists in up to 65% of adult cases (American Psychiatric Association (APA), 2013; Efron, et al., 2011). The primary symptoms of ADHD are hyperactivity, inattention, and impulsivity. The DSM-V (2013) is the standard for clinical diagnosis of ADHD. Per the DSM-V, ADHD can be divided into two types: (1) inattention and (2) hyperactivity-impulsivity; however, an individual can receive a combined diagnosis if they meet the criteria for both. For each type of ADHD, symptoms need to be present consistently for 6 months. The symptoms for the predominately inattentive type include, but are not limited to: often failing to pay close attention to detail, difficulty with sustained attention, difficulty following through on instructions or duties, easily distractible, unorganized, frequent loss of items, and forgetfulness. The symptoms for the predominately hyperactive/impulsive include, but are not limited to: frequently fidgeting or squirming, difficulty staying in place when required, restlessness, difficulty remaining quiet, excessive talking, difficulty in waiting for their turn, and interrupting often. In order to be diagnosed as an adult (17 years and older), at least five of the aforementioned symptoms must be persistent in a manner in which it inhibits typical functioning and development, occurs in at least two settings such as work and school, negatively interrupts one's ability to participate in various environments for at least six months, and cannot be explained by another mental disorder (APA, 2013). The DSM-V states symptoms of each type should exist during childhood before reaching twelve years of age. Additionally, the DSM-V recognizes although there may be a reduction in visible impairments as one enters adulthood, there remains a large percentage of adults affected by the disorder (APA, 2013). The prevalence rate of adults (17 years and older) diagnosed with ADHD worldwide is estimated to be between 2.5% and 4% (APA, 2013; Stern & Maeir, 2014).

Adults with ADHD often experience challenges within their lives affecting their academic performance, vocational opportunities, and interpersonal relationships (Harpin, 2005). The functional difficulties adults with ADHD face are shown to be associated with a reduced quality of life (Harpin, 2005; Stern & Maeir, 2014).

**Connecting Somatosensation, Speech, and Language**

There is limited research on somatosensation in adults with ADHD. What is known about somatosensory alterations in ADHD comes primarily from studies conducted in children. The majority of children diagnosed with ADHD are expected to have at least one comorbid disorder and with each additional comorbid disorder, their level of functioning will decrease as the magnitude of services increases (Larson, et al., 2011). The top five disorders seen co-occurring within this population are listed as follows with decreasing prevalence rates: learning disability, conduct disorder, anxiety, depression, and speech problems (Larson et al., 2011). In a review by Bellani and colleagues, research has shown key aspects of ADHD, such as hyperactivity or impulsiveness and inattentiveness, have a relationship with known difficulties in pragmatic and language components of communication (for full review, see Bellani, Moretti, Prlini, & Brambilla, 2011). Bellani, et al. (2011) report hyperactivity and impulsive symptoms can present in conversations and relationships (e.g., interrupting others, disregard for turn-taking, and excess talking).

Speech problems, also present in individuals with ADHD, can appear as trouble with articulation and speech sound production in a manner not suitable for one’s age, often a sign of a deficit in phonological awareness. Most noticeable during the preschool years, these difficulties can manifest as “slightly unclear or even slurred” self-expression in later years (Gillberg, 2014). As mentioned previously, individuals with ADHD often have sensory processing difficulties, but it is not known whether sensory processing difficulties affect the oral-motor area resulting in issues with speech production.

To the best of our knowledge, little research exists that investigates oral somatosensation in adults with and without ADHD and even less research on the connection between orofacial somatosensation and speech production. The primary aim of this thesis is to investigate orofacial somatosensation of adults with and without ADHD. In addition, this study will examine characteristics of speech between both groups. These aims will be investigated using two-point discrimination testing, tactile detection and discrimination testing, and collected speech samples. Between-group analyses were conducted to identify any differences in somatosensation and speech production in adults with and without ADHD. The primary research questions are:

1. Does performance on orofacial somatosensory tests and speech tasks differ between the two participant groups (ADHD and control)?
2. Is there a correlation between the outcomes on the somatosensory measures (two-point discrimination, tactile detection, & tactile discrimination), speech measures (reading accuracy and duration) and sensory profile scores?

# Chapter 3: Methodology

## Participants

Participants in this study were recruited from the Brain and Behavior Lab under the direction of lab director, Dr. Kristina Neely. These participants responded to advertisements placed throughout the State College, Pennsylvania community and were all young adults between the ages of 18 and 25 who either had a current diagnosis of ADHD or had never been diagnosed with ADHD. Exclusion criteria for this study included: (1) prior concussions which caused a loss of consciousness greater than 10 minutes; (2) prior diagnosis of seizures, epilepsy, encephalitis, meningitis, or autism spectrum disorder; (3) prior diagnosis of a musculoskeletal or neurological disorder; and (4) prior diagnosis of any disorder relating to psychosis (Neely, et al., 2017). Individuals who met the inclusion/exclusion criteria were referred to the Orofacial Physiology and Perceptual Analysis Lab (OPPAL) to complete testing.

**Adults with ADHD.** Criteria used for diagnosis of ADHD followed the procedures outlined in Neely et al. (2017) and are briefly discussed here. Participants with ADHD met DSM-V criteria, including severity and impairment across situations during one three-hour long session within the Brain and Behavior Lab (BBL), which was determined via a semi-structured interview using the Conners' Adult ADHD Diagnostic Interview (CAADID; Multi-Health Systems Inc.). Adults identified ≥ 5 symptoms of inattention (e.g., often forgetful in daily activities, difficulty organizing tasks and activities, etc.) or hyperactivity and impulsivity (e.g., unable to play or engage in leisure activities quietly, often talks excessively, often interrupts or intrudes on others, etc.) that impaired performance in a minimum of two settings (e.g. school and work) (Neely, et al., 2017). Twenty young adults (4 males, 16 females) who met the criteria for an ADHD diagnosis participated in this study. They had a mean age of 21.8 years ± 2.14 years.

No participants were taking medications at the time of the laboratory testing session. Demographic information for the ADHD group is reported in Table 1.

**Adults without ADHD.** Similar to the ADHD group, the control group also completed the CAADID during their visit to the BBL. The control participants identified < 3 total symptoms and ≤ 2 symptoms for each ADHD dimension (Neely, et al., 2017). A total of 20 young adults (10 males, 10 females) who met the criteria for the control group participated in this study. The control group had a mean age of 21.2 years ± 2.21 years. Demographic information for the control group can also be found in Table 1.

**Table 1**
*Participant demographics for ADHD and control groups.*

| Group | Age (years) | Sex | Health (1-5) | Pure Tone Hearing Tr (in dBHL) | Speech Use (1-5) |
|---|---|---|---|---|---|
| ADHD (n = 20) | 21.8 (SD 2.14) | M: 4 F: 16 | 4.15 | R: 8.46 L: 8.06 | 3.15 |
| Control (n = 20) | 21.2 (SD 2.21) | M: 10 F: 10 | 4.05 | R: 9.44 L: 8.17 | 2.75 |

Note. SD = standard deviation; M = male; F = female; Tr = threshold, hearing threshold estimates are averaged over the four frequencies of 500, 1000, 2000, and 4000 Hz.

## Procedures

Prior to the OPPAL experimental session, all participants completed a larger battery of experimental and standardized measures (Neely, et al., 2017). These additional measures included, but were not limited to a short medical history, the Connors Adult ADHD Self Report (CAARS) to assess ADHD symptoms (e.g., DSM-IV inattentive symptoms, DSM-IV hyperactive/impulsive symptoms, DSM-IV ADHD symptoms total, and an ADHD index), the Achenbach Adult Self Report (ASR) to measure symptoms of common co-occurring conditions, the Edinburgh Handedness Inventory to evaluate handedness, and sections of the Wechsler Adult

Intelligence Scale-Fourth Edition to obtain an approximation of intelligence quotient (Neely, et al., 2017). Informed written consent was obtained for each participant prior to testing in each lab. The Institutional Review Board at Pennsylvania State University approved all BBL and OPPAL procedures. All participants received monetary compensation for their time participating in this study.

In the OPPAL laboratory session, a brief case history was obtained via participant self-report prior to testing. During the case history, participants reported on the lack of any facial structural abnormalities and identified their general health on the day of testing using a 5-point categorical rating scale (scale options are: 1) poor, 2) fair, 3) good, 4) very good, and 5) excellent). Participants also responded to questions regarding: recent dental visits in the last month involving oral surgery or any local anesthetic, presence or history of speech disorder, current level of speech usage on a 5-point scale, smoking history, and history of playing brass or woodwind instruments. The Levels of Speech Usage is a self-report 5-point categorical rating scale to assess the amount, frequency, and type of speaking situations individuals face (Baylor, Yorkston, Eadie, Miller, & Amtmann, 2008) (See Appendix B for complete Speech Usage Scale). General participant demographics can be found in Table 1. Other tests conducted during the OPPAL lab visit included a speech sample, pure tone hearing threshold assessment, the Beck Anxiety Inventory (BAI) to estimate anxiety severity, and labiolingual detection and discrimination tests using Von Frey Hair monofilaments (VFH) and 2-pt discrimination discs. The same researcher conducted the research for all participants. Participants were provided with brief breaks (<5 minutes) between testing when necessary. The average time for participants in the OPPAL laboratory session ranged from approximately 90 to 120 minutes. During a visit to the Brain and Behavioral Lab, participants also completed the Adolescent/Adult Sensory Profile

(AASP), a self-report questionnaire used to identify patterns of sensory processing.

**Speech sample.** The speech sample was recorded using a Zoom H1 Handy Portable Digital Recorder to examine communication abilities at differing levels of complexity. The sample was comprised of the following: sustained vowel phonation, diadochokinetic rates (sequential/alternating motion rates), automatic/rote speech, word repetition, increasing word length, repeated trials, sentence repetition, reading of the Grandfather Passage, and production of spontaneous speech (Full speech sample protocol with examples can be found in Appendix C). In the first task, each participant was instructed to take a deep breath and hold out the vowels "ah" and "eee" for as long as possible. Three trials were obtained for each vowel. Diadochokinetic rates (sequential and alternating motion rates) were then obtained. Sequential motion rates required each participant to take a deep breath and repeat "puh" as many times as possible on one breath of air. This was then repeated with the syllables "tuh" and "kuh". Alternating motion rates were collected next in which the participant was told to repeat "puhtuhkuh" as rapidly and as accurately as possible on one breath. Participants were then asked to produce automatic or rote speech, which included counting from 1 to 20 and stating the days of the week and months of the year. The next task required each participant to repeat a series of words in which the initial and final consonant sounds remained the same such as mom, bob, nine, and roar. The following two tasks, increasing word length and repeated trials, are from the Apraxia Battery for Adults-Second Edition (ABA-2) (Dabul, 2000). For increasing word length, each participant was asked to repeat words such as "thick, thicken, thickening" and for repeated trials, each participant was asked to repeat words three times such as "Researcher: flashlight, Participant: flashlight, flashlight, flashlight." The next task required participants to repeat sentences after the researcher (e.g. "We saw several wild animals."). Participants were also asked to read the Grandfather Passage. The Grandfather Passage is often used during speech evaluations because it was created to contain almost all sounds of American English and there are associated standard norms (e.g., speed). For the final speech task of spontaneous speech, participants were asked to talk for approximately two minutes on a provided prompt, e.g. tell me about a recent vacation you've taken. Spontaneous speech allows us to examine how speech elements come together (Patel, et al., 2013). Each sample was saved using the participant's unique de-identified code and downloaded to a computer for analysis.

**Somatosensory measures.** Three somatosensory assessments were completed for bilateral lip and tongue locations. Orofacial somatosensation was assessed using two-point discrimination discs (Baseline Discrim-A-Gon; see Appendix D for example) and the Von Frey Hair monofilaments (VFHs) (Aesthesio® Precision Tactile Sensory Evaluator; see Appendix E for example). Two-point discrimination discs are octagonal and have receptors ranging from one to eight millimeters (mm) apart. The discs are also applied to the surface of the skin at a perpendicular angle, pressed down until skin was indented, and then removed. They are used to assess two-point discrimination threshold estimates. The VFH kit includes 20 nylon monofilaments of various diameters and lengths attached to a handle. VFHs are applied perpendicularly to the skin's surface and bend at the associated target force once the examiner applies pressure. The target forces for VFHs range from 0.008 to 300 grams (g); however, for the purposes of this study, the target forces used were 0.008, 0.02, 0.04, 0.07, 0.16, 0.4, 0.6, 1.0, 1.4, 2.0, 4.0, 6.0, 8.0, 10.0 and 15.0 g. Prior to beginning the study, a ceiling threshold was placed at 15.0 g to prevent any pain or harm to the participants. VFHs are used to assess tactile detection and discrimination threshold estimates.

Assessment procedures occurred in a pseudo-randomized fashion. Tactile detection threshold estimates are used to select the starting point for tactile discrimination threshold testing. Two-point discrimination and tactile detection/discrimination threshold estimates were assessed in the same bilateral lip and tongue locations. Testing was completed on the right and left lip at the midway point between lip midline and intraoral angle. The right and left tongue were tested at the point just lateral to the tip of the tongue. Participants were asked to close their eyes during testing to prevent them from seeing the type and timing of the stimulus being presented. Assessment methods used follow the procedures outlined by Etter and colleagues (Etter, Dressler, & Andreatta, 2016).

***Two-point discrimination threshold estimates.*** Two-point discrimination threshold estimates were obtained using the Baseline Discrim-A-Gon 2-Point Discriminators and a Method of Limits (MoL) approach (Gescheider, 1997). The participants were asked to identify whether they felt one or two points of pressure. If the participant felt one point of pressure, they were instructed to raise one finger, and if they felt two points of pressure, they were asked to hold up two fingers. Presentation of the stimulus started at a supramaximal level so the two points were far enough apart that the participant could positively feel two pressure locations, according to the MoL approach. All participants were able to begin at the 8mm distance. The examiner began descending trials by turning the disc to decrease the distance between the points by increments of 1 mm until the participant responded by raising one finger; the value of the distance between points was recorded. Ascending trials began at the 1mm point and the examiner turned the disc to increase the distance between points by 1 mm increments until the participant indicated he/she felt two points; the value of the distance between points was recorded. All ascending trials began at the 1mm point. To prevent the participant from guessing, the examiner would test the 1mm point between one and three times in a row before increasing the distance to 2mm. A total of six trials - three ascending and three descending – were completed. The average end point of the six trials (in millimeters) was recorded as the two-point discrimination threshold estimate.

***Tactile detection/discrimination threshold estimate.*** Tactile detection and discrimination threshold estimates were achieved using VFH monofilaments and a two-alternative forced choice paradigm. For tactile detection, the participant was instructed to select the trial, presented sequentially, containing the target stimulus. The examiner would say "trial one…trial two" in which a target stimulus was randomly applied in only one trial. The participant would then use one or two fingers to indicate the perceived presence of the target stimulus in either trial one or two, respectively. All participants began testing at the 1.4 g level based on previously published reports (Etter et al., 2017). Following the three-down one-up (3D) rule, after three correct consecutive detections, the VFH was decreased to the next target force level (Tracey, Greene, & Doty, 2012). After one incorrect detection or missed response, the VFH was increased to the next target force level. The stopping point for detection threshold values was established after five crossovers on a given force, in grams, using a staircase reversal protocol. In other words, the participants reached their threshold estimate once they were presented with a target force level five times.

For tactile discrimination, threshold estimate was determined using similar methods in detection testing. However, in the discrimination testing, participants were told they would feel a stimulus in both trials and were asked to indicate the trial in which they felt the "stronger" pressure. Discrimination trials started three levels above the participant's detection threshold estimate for each location. For example, if the left tongue detection threshold estimate was 0.008 g, then the participant would start at 0.07 g for discrimination testing. Increases and decreases in target force levels as well as stopping points were determined in the same manner as for tactile detection testing.

**Anxiety measure.** The Beck Anxiety Inventory (BAI) (Beck & Steer, 1993) (for full inventory, see Appendix F) is a 21-item inventory, which examines subjective, bodily, and pain-related symptoms of anxiety. It requires individuals to indicate how much they have been bothered by an item in the last 30 days, including the day of testing. Participants were asked to respond to items in the inventory such as experiences with numbness, fear of dying, or inability to relax. To give participants a break from somatosensory testing, the anxiety questionnaire was filled out by the participant either prior to or following the detection threshold task.

**Pure tone hearing thresholds.** Hearing thresholds were obtained bilaterally at 500, 1000, 2000, and 4000 Hz using an Interacoustics AD629 Diagnostic Audiometer and standardized assessment techniques (American Speech-Language Hearing Association(ASHA), 1978). The hearing assessment was conducted in the same quiet, comfortable room as the somatosensory testing. Participants were positioned away from the examiner with their eyes shut and with no opportunity to see the examiner's hands during testing.

**Adolescent/Adult Sensory profile (AASP).** The AASP was completed during an experimental session at the Brain and Behavior Lab. Sensory processing was assessed using the Adolescent/Adult Sensory Profile (AASP) (Brown & Dunn, 2002). This 60-item instrument asks participants to self-identify the frequency of a response to daily sensory experiences to gather information on their sensory preferences. Items included in the AASP include, "I startle easily to unexpected or loud noises", "I only eat familiar foods", "I like how it feels to get my hair cut", or "I don't get jokes as quickly as others". Each item provides information on the following quadrants: low registration, sensation seeking, sensory sensitivity, and sensation avoiding. These categories are based on Dunn's (1997) Model of Sensory Processing.

**Analysis**. All data were entered into SPSS for statistical analysis. Independent t-tests and effect sizes were calculated for the speech sample, somatosensory measures, and AASP. Means and standard deviations were evaluated at p-value = .05. Effect sizes were calculated using means and standard deviations to see how meaningful the differences were between the two groups without the confounding effect of sample size.

## Chapter 4: Results

### Speech Sample

Total time (in seconds) and total errors (number) during reading of the Grandfather Passage were recorded for each participant. Means and standard deviations by group are presented in Table 2. Independent sample *t*-tests demonstrated no significant differences in passage reading time or number of errors made between the ADHD and control group. A small effect, *d* = 0.290, was found for total number of errors produced during reading.

**Table 2**
*Means (SD) for speech measures with group comparison p-values and Cohen's d.*

| | ADHD | | Control | | ADHD vs. Control | |
|---|---|---|---|---|---|---|
| | M | SD | M | SD | p | Cohen's d |
| Speech Sample | | | | | | |
| GP Time (s) | 39.950 | 5.743 | 40.030 | 4.736 | .962 | -0.015 |
| GP Error (#) | 1.600 | 1.957 | 1.150 | 0.988 | .365 | 0.290 |

Note: Cohen's (1992) guidelines: d = 0.2, 'small' effect size; d = 0.5, 'medium' effect size; d = 0.8, 'large' effect size; $p \leq 0.05$

### AASP

An analysis on AASP raw scores was conducted to examine differences between the ADHD and control group. Statistical analyses conducted included independent sample *t*-tests and effect size calculations. Additionally, to correct for multiple comparisons, a Bonferroni correction was used. A p-value was deemed significant if it was $p < 0.0125$. For each of the sensory quadrants, the assumption of equal variances was tested and satisfied using Levene's F test. When this assumption was violated, then the more conservative p-value was used. It should also be noted that three participants did not complete the AASP. The final number of participants included in this analysis was 37.

**Table 3**
*Means (SD) for AASP scores with group comparison p-values and Cohen's d.*

| | ADHD | | Control | | ADHD vs. Control | |
|---|---|---|---|---|---|---|
| | M | SD | M | SD | p | Cohen's d |
| AASP | | | | | | |
| Low Registration | 44.941 | 8.188 | 28.600 | 4.429 | .000* | 2.482 |
| Sensation Seeking | 50.941 | 5.573 | 44.850 | 7.198 | .008* | 0.946 |
| Sensory Sensitivity | 44.882 | 6.019 | 31.100 | 6.471 | .000* | 2.205 |
| Sensation Avoiding | 42.000 | 6.324 | 35.750 | 6.804 | .007* | 0.951 |

*Note*. Cohen's (1992) guidelines: d = 0.2, 'small' effect size; d = 0.5, 'medium' effect size; d = 0.8, 'large' effect size; *p < .05
Maximum raw score for each profile is 75.

There were statistically significant group differences in the scores for all quadrants of the AASP, Low Registration ($t\ (24) = -7.36$, $p < .001$), Sensation Seeking ($t\ (35) = -2.84$, $p = .008$), Sensory Sensitivity ($t\ (35) = -6.66$, $p < .001$), and Sensation Avoiding ($t\ (35) = -2.88$, $p = .007$). When Cohen's *d* was calculated for each profile, large effects were identified for each profile: Low Registration ($d = 2.482$), Sensation Seeking ($d = 0.946$), Sensory Sensitivity ($d = 2.205$), and Sensation Avoiding ($d = 0.951$). Means, standard deviations, p-values, and Cohen's d for each of the AASP quadrants is presented in Table 3.

**Somatosensation Measures**

To investigate whether adults with and without ADHD demonstrated significant differences in threshold estimates on 2-pt detection, tactile detection, and tactile discrimination, independent sample *t*-tests were conducted. To correct for three comparisons, a Bonferroni correction was used. A p-value was deemed significant if it was $p < 0.004$. For each of the three orofacial somatosensory test conditions, the assumption of equal variances was tested and satisfied using Levene's *F* test. When this assumption was violated, then a more conservative p-value was used. Effect sizes were also calculated for each assessment measure by body location.

Means, standard deviations, p-values and effect sizes for all three conditions are displayed in Table 4.

**Two-point discrimination threshold estimates.** Adults with ADHD demonstrated lower threshold estimates than the adults without ADHD across all locations; however, no significant differences were found. A small effect size, $d = 0.317$, was identified for the left lip location. A graphical representation of the means and the 95% confidence intervals is displayed in Fig. 1a.

**Tactile Detection Threshold Estimates.** As displayed in Fig. 1b, adults with ADHD had higher threshold estimates than the control group on three out of four locations (not including left lip). No significant differences were identified between both groups. Similarly, when Cohen's *d* was calculated for each testing location, none reached the level of a small effect size.

**Tactile Discrimination Thresholds Estimates.** As reported in Fig. 1c, adults with ADHD demonstrated higher threshold estimates compared to the control group on the right lip, left lip, and right tongue; however, for the left lip, both groups performed similarly. Tests revealed no statistically significant differences between both groups. Interestingly though, there was evidence of trending towards significance with the right tongue ($t\ (19.218) = -2.08$, $p = .051$). However, once the Bonferroni correction was applied, it was no longer significant. When effect sizes were calculated for all body locations between groups, medium effect sizes were found for two locations: Right Lip ($d = -0.456$) and Right Tongue ($d = -0.657$). A small effect size, $d = 0.365$, was found for left lip between both groups. No effect was found for left tongue.

**Table 4**
*Threshold estimate means (SD) by testing condition and location with group comparisons.*

| | ADHD | | Control | | ADHD vs. Control | |
|---|---|---|---|---|---|---|
| | M | SD | M | SD | p | Cohen's d |
| Somatosensory Measures | | | | | | |
| 2-pt Discrimination | | | | | | |
| Right Lip | 3.041 | 0.471 | 3.125 | 0.664 | .648 | 0.145 |
| Left Lip | 2.766 | 0.827 | 3.017 | 0.752 | .322 | 0.317 |
| Right Tongue | 2.966 | 0.788 | 3.089 | 0.897 | .647 | 0.145 |
| Left Tongue | 2.957 | 0.729 | 3.109 | 1.051 | .598 | 0.167 |
| Detection Thresholds | | | | | | |
| Right Lip | 0.013 | 0.008 | 0.011 | 0.013 | .683 | -0.184 |
| Left Lip | 0.010 | 0.004 | 0.010 | 0.007 | .847 | 0.061 |
| Right Tongue | 0.010 | 0.004 | 0.009 | 0.004 | .687 | -0.128 |
| Left Tongue | 0.012 | 0.008 | 0.011 | 0.008 | .646 | -0.146 |
| Discrimination Thresholds | | | | | | |
| Right Lip | 0.132 | 0.225 | 0.058 | 0.036 | .164 | -0.456 |
| Left Lip | 0.649 | 2.243 | 0.069 | 0.046 | .262 | 0.365 |
| Right Tongue | 1.001 | 1.926 | 0.103 | 0.145 | .051* | -0.657 |
| Left Tongue | 0.363 | 0.959 | 0.361 | 0.646 | .992 | -0.003 |

*Note*: Cohen's (1992) guidelines: d = 0.2, 'small' effect size; d = 0.5, 'medium' effect size; d = 0.8, 'large' effect size; *p < .05, ***p < 0.004

**Correlation Analysis**

To assess the relationship between the speech sample, AASP scores, and somatosensory measures across participants, Pearson correlation analyses were conducted on a variety of variables including the AASP quadrant scores, grandfather passage reading time and errors, and somatosensory thresholds. The analyses were completed in three steps.

The first analysis was conducted to examine the relationship between the grandfather passage (time and total number of errors) and the three somatosensory measures (2pt, tactile detection and discrimination). As shown in Table 5, two significant correlations ($p < .05$) were found. There was a positive correlation between passage reading time and 2-pt discrimination on the left tongue location, $r$ (40) = 0.333, p = .036, such that as reading duration increased so did their discrimination thresholds. There was a negative correlation between passage number of errors and 2-pt discrimination on the right lip location, $r$ (40) = -0.317, p = .046, such that as number of errors made increased, then their discrimination thresholds decreased. No other significant correlations were found between the remaining variables.

Next, we examined the relationship between the quadrant scores from the AASP and the three somatosensory measures. As shown in Table 6, two significant correlations were identified. There was a positive correlation between Sensation Seeking and tactile detection on the left tongue location, $r$ (37) = 0.341, p = .039, such that as over-responsive behaviors increased so did detection thresholds. There was a positive correlation between Sensation Seeking and tactile discrimination on the right tongue location, $r$ (37) = 0.341, p = .039, such that as over-responsive behaviors increased so did discrimination thresholds. Significant correlations were not found between the remaining somatosensory and sensory profile variables.

Last, we examined the relationship between the AASP quadrants and speech measures. No significant correlations were identified, all ps > X (.05).

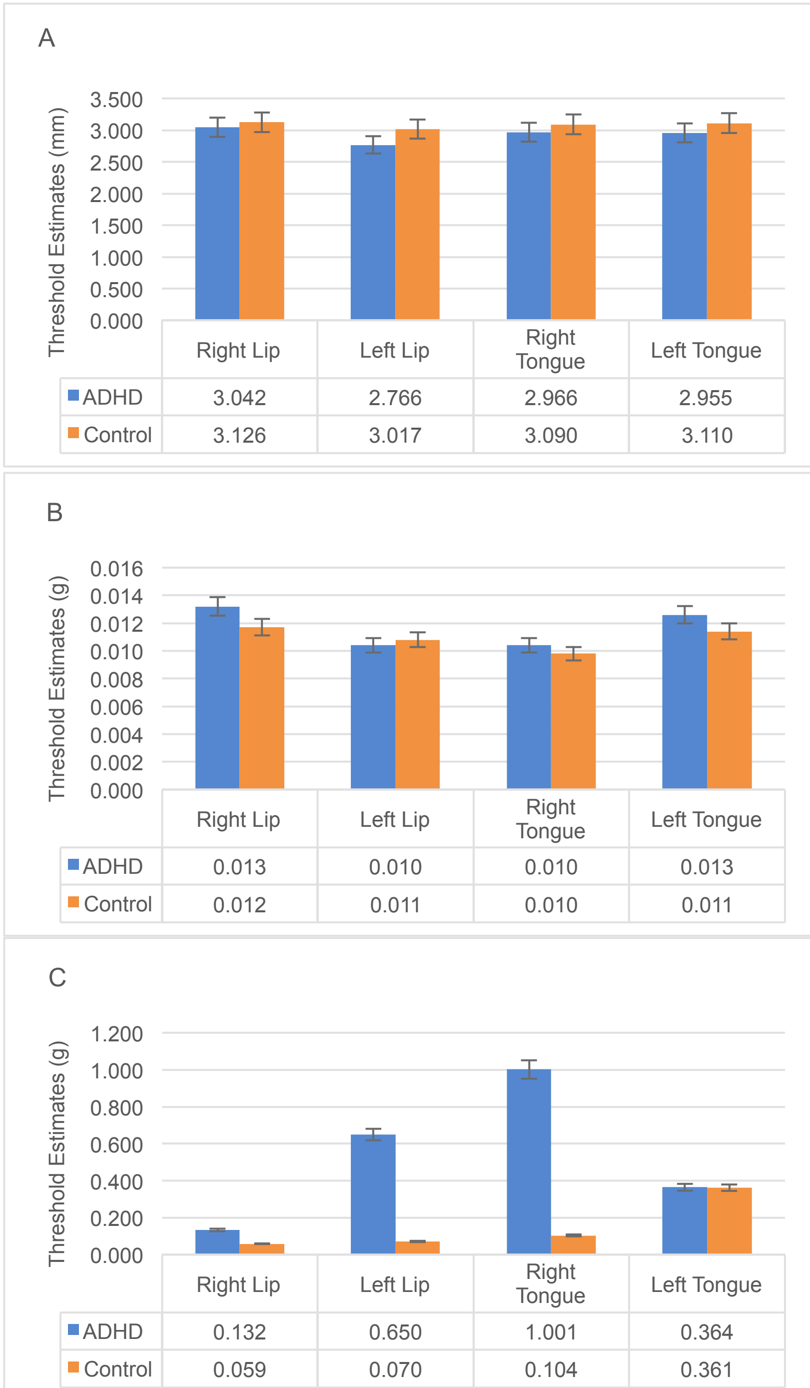


Fig 1. Somatosensory threshold estimates for the ADHD and control group. (A) Adults with ADHD demonstrated lower threshold estimates across body locations in 2-pt discrimination. (B) Adults with ADHD had higher threshold estimates across three body locations, but not left lip, in tactile detection when compared to the control group. (C) Adults with ADHD demonstrated higher threshold estimates across three body locations, but not left tongue, in tactile discrimination.

**Table 5**
*Pearson correlations of passage time and number of errors with somatosensory measures.*

| Somatosensory measures | Passage Time | Passage Errors |
|---|---|---|
| Two-point discrimination | | |
| Right Lip | .139 | -.317* |
| Left Lip | .257 | -.162 |
| Right Tongue | -.186 | -.153 |
| Left Tongue | .333* | -.111 |
| Tactile Detection | | |
| Right Lip | .159 | -.152 |
| Left Lip | .038 | -.214 |
| Right Tongue | -.056 | -.027 |
| Left Tongue | .107 | -.065 |
| Tactile Discrimination | | |
| Right Lip | -.162 | -.083 |
| Left Lip | -.226 | -.049 |
| Right Tongue | -.265 | .215 |
| Left Tongue | .040 | .097 |

*Note.* $N = 40$; Pearson correlations with $p < .05$ are noted with an asterisk (*).

**Table 6**
*Pearson correlations of AASP quadrants with somatosensory measures.*

| Somatosensory measures | Low Registration | Sensation Seeking | Sensory Sensitivity | Sensation Avoiding |
|---|---|---|---|---|
| Two-point discrimination | | | | |
| Right Lip | -.036 | -.013 | .064 | .256 |
| Left Lip | -.164 | -.007 | .036 | -.034 |
| Right Tongue | .005 | .038 | -.043 | .147 |
| Left Tongue | .061 | -.046 | .091 | .126 |
| Tactile Detection | | | | |
| Right Lip | .088 | .095 | .257 | .088 |
| Left Lip | .101 | .123 | .219 | .132 |
| Right Tongue | -.047 | .064 | .123 | -.028 |
| Left Tongue | .156 | .341* | .231 | .196 |
| Tactile Discrimination | | | | |
| Right Lip | .005 | .114 | .227 | .207 |
| Left Lip | -.064 | .099 | .152 | .109 |
| Right Tongue | .249 | .341* | .250 | .200 |
| Left Tongue | .000 | .120 | .008 | .110 |

*Note.* $N = 37$; Pearson correlations with $p < .05$ are noted with an asterisk (*).

# Chapter 5: Discussion

Little is currently known about the impact ADHD has on orofacial somatosensation and speech motor tasks. Our findings begin to provide insights in this area. First, on speech measures, reading time and accuracy were not significantly different for the ADHD group when compared to the control group. Second, on somatosensory measures, two-point discrimination, tactile detection, and tactile discrimination were also not significantly different for adults with ADHD compared to adults without ADHD. Third, regarding sensory processing patterns, adults with ADHD identified greater sensitivity to everyday sensory experiences within all four quadrants compared to adults without ADHD, particularly in low registration and sensory sensitivity. Fourth, threshold estimates on two-point discrimination left tongue and two-point discrimination right tongue were correlated to reading time and reading accuracy, respectively. Fifth, threshold estimates for tactile detection left tongue and tactile discrimination right tongue were stronger predictors of the sensory sensitivity quadrant compared to threshold estimates on the remaining testing conditions and body locations.

## Speech Sample

The absence of a significant group difference for reading time and accuracy demonstrates adults with ADHD do not have abnormal oral somatosensation or that these speech measures do not have fine enough resolution to detect abnormal oral tactile sensation. A visual inspection of the means shows a trend such that adults with ADHD read the passage more quickly and were less accurate than adults without ADHD. There is no consensus in the literature regarding reading time and accuracy for people with ADHD. In regards to reading speed, Miranda, Mercader, Fernandez, and Colomer (2013) found that young male adults, 18 to 24 years old, with ADHD read at significantly slower speeds than their counterparts which they attributed to impairments in executive functioning and little reading practice. On the other hand, Laasonen, Lehtinen, Leppämäki, Tani, and Hokkanen (2010) found similar results to the current study where adults, 18 to 55 years old, with ADHD read at speeds comparable to the control group. This discrepancy could be due to the fact that only one reading passage was utilized in the present study. In studies by Engelhardt et al. (2010) and Miranda et al. (2013), they also found adults with ADHD to have decreased accuracy which supports the findings of this present study, although ours did not reach the level of statistical significance.

**AASP**

Adults with ADHD self-reported more sensory behavior responses within all four quadrants of the AASP compared to adults with ADHD. When comparing Dunn's (1997) model of sensory processing to Miller et al.'s, (2007) proposed classification, there are parallels between low registration and sensory under-responsivity (SUR) as well as between sensory sensitivity and sensory over-responsivity (SOR). If one is looking for impairments in sensory processing within the adults in the present study, then one could propose adults with ADHD fall under SUR and SOR. Individuals who have SUR are passive in their responses and are less likely to react to incoming sensory information. One could propose that failure to react to stimuli may be related to inattentive symptoms of ADHD, possibly suggesting adults with this subtype could have SUR. Individuals who have SOR are more responsive to incoming stimuli in a manner that is quicker, prolonged, or more extreme. When you compare it to sensory sensitivity whose characteristics can include distractibility and hyperawareness, they are similar to the symptoms associated with the predominately hyperactive/impulsive subtype of ADHD. Since both processes of SUR and SOR are possibly present in the ADHD group of this study, one could make the claim that there may be a presence of a processing disorder.

## Somatosensation Measures

**Two-point Discrimination Threshold Estimates.** Both participant groups performed comparably on two-point discrimination. Since participants within each group were young, in good health with no adverse structural impairments within their orofacial regions, it is not surprising there are no significant differences in the size of their receptor fields. The small effect size that was found for left lip may suggest a difference in individuals with ADHD. However, this may be explained due to this assessment being completed first.

**Tactile Detection Threshold Estimates.** Adults with ADHD had overall slightly higher threshold estimates compared to adults without ADHD, implying worse sensation with tactile perception. This is in agreement with what Scherder, et al. (2008) found in children with ADHD in which they made more errors on light touch than their siblings without ADHD. However, since no significant difference was found between the ADHD and control group in the present study, it appears tactile sensory perception is not impaired.

**Tactile Discrimination Threshold Estimates.** Similar to the tactile detection task, adults with ADHD overall presented with higher threshold estimates compared to adults without ADHD. Higher thresholds might indicate adults could not tell the difference between applied target forces within one step of each other. In a study of temperature discrimination in children with ADHD, children with ADHD were worse or less sensitive than their peers; (Scherder, et al., 2008); however it is notable that temperature sensation relies on thermoreceptors and not mechano. Scherder and colleagues suggest that the poor performance could be attributed to lower sensitivity for thermal sensory stimuli. Taking into consideration Miller et al.'s (2007) SPD classification system, this suggests evidence of SDD or sensory discrimination disorder.

## Correlations

Two significant positive relationships were found between (1) the AASP quadrant of sensation seeking and tongue tactile detection and (2) sensation seeking and tactile discrimination on the tongue. This is consistent/inconsistent with the literature. For example, Bijlenga, Tjon-Ka-Jie, Schuijers, and Kooij (2017) studied the presence of altered sensory sensitivity in adults between the ages of 18 and 64. In Bijlenga et al.'s (2017) study, altered sensory sensitivity included hypersensitivity, which referred to people who had high scores in the sensory sensitivity quadrant of the AASP and hyposensitivity, which referred to people who scored high in the low registration quadrant. Similar to the results of this present study, Bijlenga et al. (2017) found the ADHD group with more low registration to incoming sensory stimuli implying hyposensitivity. However, adults in this current study reported more sensation seeking behaviors where the adults in Bijlenga et al.'s (2017) study identified with less sensation seeking behaviors. Bijlenga's work suggests adults with ADHD actively seek sensation in an attempt to arouse their hyposensitivity (low registration of stimuli) (Bijlenga et al., 2017), and as they do so, they may also experience higher threshold estimates on both detection and discrimination measures seen within this study. These results are in accordance with the clinical presentation of ADHD where sensation seeking behavior is a common symptom of the disorder. Other studies demonstrate the presence of both hypo- and hypersensitivity or what can also be thought of as sensory under- and over- responsivity in individuals with ADHD.

## Limitations

The findings of this study contribute to a small body of research examining somatosensation and speech in adults with ADHD. There are several limitations of the current work. First, the current study examined somatosensation in a young and neurologically healthy group of individuals. However, other work shows there are age-related changes in somatosensation (Bowden & McNulty, 2013; Teranaka, Shibaji, Minakuchi, & Uematsu, 2008). Future work may want to expand age ranges. Second, markers were not utilized when using discrimination discs and monofilaments to test the bilabial lip and tongue locations. Therefore the same placement location for testing cannot be guaranteed every time. The methods used in the current work closely resembles methods used in clinical settings and, therefore, should be considered to be a strength of this study as in increases clinical applicability. Third, although each tester was instructed in the same manner by the principal investigator, the amount of pressure administered by each individual could have differed from trial to trial and from researcher to researcher, which in turn could have affected the responses given by the participants. Fatigue or numbing of the tissues in one test location could occur from presenting the discs and monofilaments in the same location each trial, to counteract this, participants were instructed to move around or take a drink in between testing locations. Finally, the current work examines a small sample, which is common within the speech pathology discipline.  The current study was completed as part of a larger experimental study and it is assuring that patterns of sensory processing are visible in a small sample.

**Clinical Implications**

The results of this study suggest adults with ADHD may have sensory hyposensitivity, but the objective somatosensory measures used in the present study do not appear to be related to speech performance. This might suggest our somatosensory or speech measures were not sensitive enough to detect any deficits in this relationship. However, our sensory tools (2-pt discrimination discs and VFHs), can help to rule out somatosensation deficits as the cause of one's speech problems since the present study showed orofacial somatosensation in adults with

ADHD were not different from adults without ADHD. It may be useful for SLPs to complete the AASP with their clients as knowledge of one's sensory preferences can help to guide treatment sessions. Sensory preferences can inform how sessions are structured to perhaps provide a less or more stimulating environment for an individual to be productive.

**Future Directions**

Future work should focus on the relationship between somatosensation and sensory processing, which is best explained via a larger cohort of age- and sex- matched participants. The effect of sex on somatosensory and speech measures could also be looked at since there is an evidence base that shows sex differences in sensorimotor control. In addition, analyses of other speech data collected in the speech sample, such as diadochokinetic rate or spontaneous speech, should also be considered for future research. This study adds to the literature by exploring the relationship between orofacial somatosensation, speech measures, and sensory processing in adults with and without ADHD.

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## Appendix A

## Case History Form

**Date:** ________________ **Experimenter:** _______________ **Participant initials:** ___________

**Handedness:** ___________ **Sex:** __________ **Age:** __________ **DOB:** __________

| | |
|---|---|
| **Neurologic Injury? (Describe in detail)** | |
| **Occupation** | |
| **General health today? (5 is best)** | 1 2 3 4 5 |
| **Recent dental work? (<1month)** | |
| **Health of lower face?** | |
| **Diabetic? Insulin?** | |
| **Smoking history?** | |
| **How much? How often?** | |
| **When was the last time?** | |
| **Difficulty hearing?** | Circle: Y / N 1:1 Conversation Noisy Environment |
| **Hearing aids?** | Circle: Y / N Bilateral? Left? Right? |
| **How long have you had them?** | |
| **How often do you wear them?** | |
| **Ever had difficulty w/ speech?** | |
| **Value Indicated on the Speech Usage Scale?** | |
| **Ever played musical instrument?** | |

**Comments about testing session:**

| | **Hearing Thresholds** | |
|---|---|---|
| | **RIGHT** | **LEFT** |
| **500** | | |
| **1,000** | | |
| **2,000** | | |
| **4,000** | | |

## Appendix B

## Baylor Speech Usage Scale

Choose the category below that best describes you:

_____ **1. Undemanding:**
Quiet for long periods of time almost every day.
<u>Almost never</u>
• talk for long periods
• raise your voice above a conversational level,
• participate in group discussions, give a speech or other presentation

_____ **2. Intermittent:**
Quiet for long periods of time on many day.
Most talking is typical conversational speech.
<u>Occasionally:</u>
• talk for longer periods
• raise voice above conversational level
• participate in group discussions, give a speech or other presentation

_____ **3. Routine:**
Frequent periods of talking on most days
Most talking is typical conversational speech
<u>Occasionally:</u>
• talk for longer periods
• raise voice above conversational level
• participate in group discussions, give a speech or other presentation

_____ **4. Extensive:**
Speech usage consistently goes beyond everyday conversational speech.
<u>Regularly:</u>
• talk for long periods
• talk in a loud voice
• participate in group discussions, give presentations or performances
*The demands of your speech are often high, you are able to continue with most work or social activities even if your speech is not perfect.*

_____ **5. Extraordinary:**
Very high speech demands
<u>Regularly:</u>
• talk for long periods of time
• talk with loud or expressive speech or
• give presentations or performances.
*The success of your work or personal goals depends almost entirely on the quality of your speech and voice.*

## Appendix C

## Speech Sample Protocol

- **Sustained vowel /a/ and /i/**
  - "Take a deep breath and hold the vowel /xx/ for as long as you can"
  - Repeat x3 for each vowel
- **Sequential Motion Rates (SMRs)**
  - /pa/ /ta/ /ka/
  - "Take a deep breath and repeat /##/ for as long as you can"
  - Repeat with all three CV combinations
- **Alternating Motion Rates (AMRs)**
  - /pataka/
  - "Take a deep breath and repeat /pataka/ as fast/ accurately as possible
- **Automatics**
  - Count 1 -20
    - "Please count 1 to 20"
  - Days of the week
    - "Please say the days of the week starting with Monday"
  - Months of the year
    - "Please say the months of the year starting with January"
- **Word Repetition**
  - Repeat after me
    - Mom
    - Bob
    - Nine
    - Coke
    - Peep
    - Sis
    - Shush
    - Roar
- **Words of increasing length**
  - "I'm going to say some words. You repeat what I say"
    - See below
- **Repeated Trials/ Multisyllabic words**
  - "I'm going to say some words. I'll say each word one time and then you say it three times"
    - See below
- **Sentences**
  - Repeat after me:
    - We saw several wild animals
    - My physician wrote out a prescription
    - The municipal judge sentenced the criminal
- **Grandfather paragraph**
  - "Here is a short passage that seems a little silly. It was written to include most of the sounds in the English language. Please read the paragraph to me"
    - See below
- **Story telling**
  - "Tell me about a vacation you've taken"

**Grandfather Passage**

You wish to know all about my grandfather. Well he is nearly 93 years old, yet he still thinks as swiftly as ever. He dresses himself in an old black frock coat, usually with several buttons missing. A long beard clings to his chin, giving those who observe him a pronounced feeling of the utmost respect. Twice each day he plays skillfully and with zest upon a small organ. Except in the winter when the snow or ice prevents, he slowly takes a short walk in the open air each day. We have often urged him to walk more and smoke less, but he always answers, “Banana oil!” Grandfather likes to be modern in his language

# of words: 115
~ 35-50 seconds

## Repeated Trials/Multisyllabic words

| | | | | |
|---|---|---|---|---|
| **Repeated Trials** | | | | |
| **Instructions:** | **'I'm going to say some words. I'll say each word one time and then you say it three times"** | | | |
| **Scoring:** | Record the number of errors for each trial (1-3) and, in the far right column record the following score: | | | |
| | **"+"** | more errors in trial 1 vs 3 | | |
| | **"–"** | fewer errors in trial 1 vs 3 | | |
| | **"0"** | same number of errors in trials 1 and 3 | | |

| **Word** | **Trial 1** | **Trial 2** | **Trial 3** | **Trials 1 and 3 Compared** |
|---|---|---|---|---|
| Example: telephone | | | | |
| flashlight | | | | |
| umbrella | | | | |
| newspaper | | | | |
| banana | | | | |
| elephant | | | | |
| potatoes | | | | |
| butterfly | | | | |
| motorcycle | | | | |
| computer | | | | |
| refrigerator | | | | |

**Total Amount of Change = Number of "+" – Number of "–" = _______________**

**Variability = total number of + and – marks (max of 10) = ______________**

**Raw Score = 30 – number of words with errors = ______________**

## Words of Increasing Length

| A. Increasing Word Length | | | | | | ID / Date | | |
|---|---|---|---|---|---|---|---|---|
| **Instructions:** | **"I'm going to say some words. You repeat what I say"** | | | | | | | |
| | Present the first word and pause while the examinee repeats, then present the second word etc. Say each word only once. The examinee may watch your face as you say each word. | | | | | | | |
| **Scoring:** | 2 | correct response without hesitation or struggle or articulatory error | | | | | | |
| | 1 | self-corrects, delays significantly, displays visible/aduible searching, one or more articulatory errors, but maintains the correct number of syllables and general conformation of the word | | | | | | |
| | 0 | no response, attempts but does not produce a word, says the wrong number of syllables, or misarticulates to the extent that the word is no longer recognizable | | | | | | |
| ***Examples:*** | *thicken* | *response: thick* | *score: 0* | | | | | |
| | *thicken* | *response: thicklen* | *score: 1* | | | | | |

| Column 1 | Response | Score | Column 2 | Response | Score | Column 3 | Response | Score |
|---|---|---|---|---|---|---|---|---|
| thick | | | thicken | | | thickening | | |
| zip | | | zipper | | | zippering | | |
| jab | | | jabber | | | jabbering | | |
| please | | | pleasing | | | pleasingly | | |
| love | | | loving | | | lovingly | | |
| hard | | | harden | | | hardening | | |
| jig | | | jiggle | | | jiggling | | |
| strength | | | strengthen | | | strengthening | | |
| hope | | | hopeful | | | hopefully | | |
| soft | | | soften | | | softening | | |
| **Total** | | **0** | **Total** | | | **Total** | | **0** |

**Deterioration in Performance Score (Col 1 total - Col 3 total) = ____________** 0

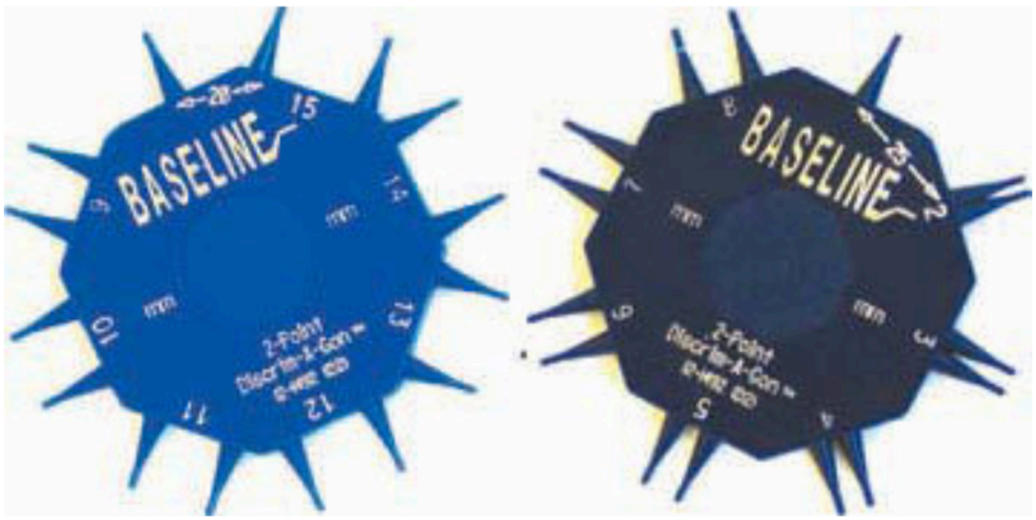
| B. Increasing Word Length (do not administer if scored moderate or severe in Part A) | | | | | | ID / Date | | |
|---|---|---|---|---|---|---|---|---|
| **Instructions:** | **"I'm going to say some words. You repeat what I say"** | | | | | | | |
| | Present the first word and pause while the examinee repeats, then present the second word etc. Say each word only once. The examinee may watch your face as you say each word. | | | | | | | |
| **Scoring:** | 2 | correct response without hesitation or struggle or articulatory error | | | | | | |
| | 1 | self-corrects, delays significantly, displays visible/aduible searching, one or more articulatory errors, but maintains the correct number of syllables and general conformation of the word | | | | | | |
| | 0 | no response, attempts but does not produce a word, says the wrong number of syllables, or misarticulates to the extent that the word is no longer recognizable | | | | | | |
| ***Examples:*** | *thicken* | *response: thick* | *score: 0* | | | | | |
| | *thicken* | *response: thicklen* | *score: 1* | | | | | |

| Column 1 | Response | Score | Column 2 | Response | Score | Column 3 | Response | Score |
|---|---|---|---|---|---|---|---|---|
| instruct | | | instructive | | | instructively | | |
| attract | | | attractive | | | attractively | | |
| city | | | citizen | | | citizenship | | |
| beauty | | | beautiful | | | beautifully | | |
| response | | | responsible | | | responsibility | | |
| dispose | | | disposable | | | disposability | | |
| democrat | | | democratic | | | democratically | | |
| emotion | | | emotional | | | emotionally | | |
| character | | | characteristic | | | characteristically | | |
| national | | | nationalistic | | | nationalistically | | |
| The man at the computer was typing | | | They said the man at the computer was typing quickly | | | I'm not sure if they said that the man at the computer was typing quickly or slowly | | |
| **Total** | | | **Total** | | | **Total** | | |

**Deterioration in Performance Score (Col 1 total - Col 3 total) = ______________**

**Appendix D**

Baseline Discrim-A-Gon



## Appendix E

Aesthesio® Precision Tactile Sensory Evaluator

**Appendix F**

Beck Anxiety Inventory (BAI)

Below is a list of common symptoms of anxiety. Please carefully read each item in the list. Indicate how much you have been bothered by that symptom during the past month, including today, by circling the number in the corresponding space in the column next to each symptom.

| | Not At All | Mildly but it didn't bother me much | Moderately - it wasn't pleasant at times | Severely – it bothered me a lot |
|---|---|---|---|---|
| Numbness or tingling | ☐ | ☐ | ☐ | ☐ |
| Feeling hot | ☐ | ☐ | ☐ | ☐ |
| Wobbliness in legs | ☐ | ☐ | ☐ | ☐ |
| Unable to relax | ☐ | ☐ | ☐ | ☐ |
| Fear of worst happening | ☐ | ☐ | ☐ | ☐ |
| Dizzy or lightheaded | ☐ | ☐ | ☐ | ☐ |
| Heart pounding/racing | ☐ | ☐ | ☐ | ☐ |
| Unsteady | ☐ | ☐ | ☐ | ☐ |
| Terrified or afraid | ☐ | ☐ | ☐ | ☐ |
| Nervous | ☐ | ☐ | ☐ | ☐ |
| Feeling of choking | ☐ | ☐ | ☐ | ☐ |
| Hands trembling | ☐ | ☐ | ☐ | ☐ |
| Shaky / unsteady | ☐ | ☐ | ☐ | ☐ |
| Fear of losing control | ☐ | ☐ | ☐ | ☐ |
| Difficulty in breathing | ☐ | ☐ | ☐ | ☐ |
| Fear of dying | ☐ | ☐ | ☐ | ☐ |
| Scared | ☐ | ☐ | ☐ | ☐ |
| Indigestion | ☐ | ☐ | ☐ | ☐ |
| Faint / lightheaded | ☐ | ☐ | ☐ | ☐ |
| Face flushed | ☐ | ☐ | ☐ | ☐ |
| Hot/cold sweats | ☐ | ☐ | ☐ | ☐ |