Evaluation of Motor Speech and Intervention Planning for Children with Autism

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EVALUATION OF MOTOR SPEECH AND INTERVENTION PLANNING FOR CHILDREN WITH AUTISM

A Dissertation Presented

by

MARCIL J. BOUCHER

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DEDICATION

To my favorite “little man,” may we someday know how to help you more.

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I would like to express my appreciation and gratitude for all who have helped this project reach completion. To Dr. Mary Andrianopoulos, my dissertation chair, thank you for all your help and guidance along the way. Thank you also to Drs. Shelley Velleman and Lisa Keller, your feedback and support were essential. Without the support of my dissertation committee I would not have been able to complete this.

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Finally, I would like to thank the families of the children who participated in the study. Thank you for taking time out of your busy and hectic lives to participate in this study. Hopefully one day we will all reach a better understanding of autism, and the puzzle pieces will all fall into place.

ABSTRACT

EVALUATION OF MOTOR SPEECH AND INTERVENTION PLANNING FOR CHILDREN WITH AUTISM

MAY 2013

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Autism affects 1 in 88 children (Center for Disease Control, 2009), approximately 50% of whom will not develop speech (Seal & Bonvillian, 1997). Some researchers hypothesize that these difficulties in developing oral speech reflect underlying motor speech deficits (Prizant, 1996; Seal & Bonvillian, 1997; Szypulski, 2003; Andrianopoulos, Boucher, Velleman & colleagues 2007-2010). This investigation sought to identify the presence or absence of specific motor speech markers in ASD through an innovative best-practice protocol for assessing the speech, prosody, and voice quality of individuals with ASD.

The study focused on apraxic-like motor planning/programming features and dysarthric-like motor execution features in imitated, elicited, and spontaneous speech in 15 children with ASD between 4;0 and 12;11 years as compared to 15 children who were NTD.

Speech analyses included imitated speech tasks for [f] and [a] prolongation, the short phrase “pea tea key” and AMRs and SMRs; elicited speech tasks for Counting 1-10 and singing Happy Birthday; along with spontaneous speech tasks for telling two stories based on wordless picture stories and discussing a topic of interest.

Results indicated that children with ASD presented with significantly decreased Maximum Phonation Times; lower formant values; lower pitch values; decreased rate of speech characterized by increased utterance, pause and vowel durations; reduced number of syllable repetitions in AMR and SMR tasks; variable and/or inconsistent performance across tasks; and a mildly deviant voice, further characterized by mildly deviant levels of roughness and strain, atypical production of prosody and inconsistent nasality.

Based on the results of this empirical investigation, an acoustic-perceptual and motor speech profile for a sample population of children with an autism spectrum disorder can be determined by six tasks: prolongation of [f] and [a], articulation of AMRs and SMRs, Counting 1-10, and telling a story based on a wordless picture book. These objective measures can empirically determine the presence, prevalence, and nature of speech, phonatory, and prosodic deficits in this sample population. They support that intervention for children with ASD should not only focus on pragmatics, MLU, and vocabulary, as is often the case. Rather, voice and motor speech intervention protocols should be incorporated as appropriate to individuals with autism.

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REVIEW OF THE LITERATURE

1.1. Autism

Autism affects 1 in 88 children (Center for Disease Control (CDC), 2009), with a recent survey of parents suggesting that this number may be rising to as much as 1 in 50 children (CDC, 2013), a definite increase from the previous prevalence statistic of 1 in 150 (Autism Society of America, 2007). A new case is diagnosed every 20 minutes, making it the fastest growing serious developmental disability in the United States (Autism Speaks, 2006). It is now the second most common developmental disability, after mental retardation and before cerebral palsy (Center for Disease Control and Prevention, 2006).

Autism is a complex developmental disorder, most commonly diagnosed by psychologists according to the criteria set forth in the Diagnostic and Statistical Manual of Mental Disorder- IV (DSM-IV) (American Psychiatric Association, 1994):

I. A total of six (or more) items from (A), (B), and (C), with at least two from (A), and one each from (B) and (C).
   A. Qualitative impairment in social interaction, as manifested by at least two of the following:

    1. Marked impairments in the use of multiple nonverbal behaviors such as eye-to-eye gaze, facial expression, body posture, and gestures to regulate social interaction.
    2. Failure to develop peer relationships appropriate to developmental level.
    3. A lack of spontaneous seeking to share enjoyment, interests, or achievements with other people, (e.g., by a lack of showing, bringing, or pointing out objects of interest to other people).
    4. Lack of social or emotional reciprocity

B. Qualitative impairments in communication as manifested by at least one of the following:
    1. Delay in, or total lack of, the development of spoken language (not accompanied by an attempt to compensate through alternative modes of communication such as gesture or mime).
    2. In individuals with adequate speech, marked impairment in the ability to initiate or sustain a conversation with others.
    3. Stereotyped and repetitive use of language or idiosyncratic language.
    4. Lack of varied, spontaneous make-believe play or social imitative play appropriate to developmental level.

C. Restricted, repetitive and stereotyped patterns of behavior, interests and activities, as manifested by at least two of the following:
    1. Encompassing preoccupation with one or more stereotyped and restricted patterns of interest that is abnormal either in intensity or focus.
    2. Apparently inflexible adherence to specific, nonfunctional routines or rituals.
    3. Stereotyped and repetitive motor mannerisms (e.g., hand or finger flapping or twisting, or complex-whole body movements).

        4. Persistent preoccupation with parts of objects.

II. Delays or abnormal functioning in at least one of the following areas, with onset prior to age 3 years:
    A. Social interaction
    B. Language as used in social communication
    C. Symbolic or imaginative play

III. The disturbance is not better accounted for by Rett’s Disorder or Childhood Disintegrative Disorder. (p. 75)

Autism and autism spectrum disorders (ASDs) can vary greatly from one individual to the next. This is due largely in part to the lack of a definitive medical diagnosis, such as the Trisomy of Chromosome 21 that is known to be the cause of Down syndrome. The most common chromosomal abnormality found to date within people with autism is a microduplication of chromosome 15q11-q13, found with a frequency between one percent (Boyar, 2001) and three percent (Autism Genome Project Consortium, 2007) of the studied population of individuals with autism.

It is pertinent for professionals who come in contact with individuals on the autism spectrum to possess a thorough understanding of the disorder. For Speech-Language Pathologists (SLPs) in particular, there is an immense increase in the number of children with autism seeking their services (Diehl, 2003). Speech-Language Pathologists generally encounter two distinctive groups of children with autism: those who have speech and those who do not have speech.

It is widely believed, and supported by numerous facts, that children with autism possess the capability to communicate. Several studies have discovered that verbal children with autism commonly follow the same paths of development as found within typical children (Baltaxe & D’Angiola, 1992; Cohen & Donnellan, 1987; Tager-Flusberg, Calkins, Nolin, Baumberger, Anderson, & Chadwick-Dias 1990; Williams, 1993, cited by Adams, 1998). This suggests that once children with autism begin to develop language, their language may develop typically but at a slower, or atypical rate. The steps to reach an effective beginning of language development may be the most difficult. However, children with ASD who do develop oral communication nonetheless demonstrate moderately increased risks of speech delay/disorder at early ages and significantly higher risks of speech errors in later childhood, as well as abnormalities of prosody and voice (Paul, Augustyn, Klin & Volkmar, 2005; Peppe, McCann, Gibbon, O’Hare & Rutherford, 2007; Wing, 1996; Zajac, Roberts, Harris, Barnes & Misenheimer, 2006).

Amongst the population of children with autism who communicate orally, the speech present has been described as being “bizarre” (Fay & Schuler, 1980; McCann & Peppé, 2003). These atypical speech and vocal features can contribute to the difficulties children with autism encounter in both the language-use and the speech production aspects of oral communication.

A common language-use problem that is frequently seen in children with autism is echolalia. Echolalia is defined as “the immediate or delayed imitation of verbally-presented stimuli, a high frequency characteristic in autism,” (Richard, 1997, p. 16). When children with autism present with echolalia, they will repeat utterances that have been produced by a parent, teacher, on television, etc., either immediately, or after a period of time (Foreman, 2006). The presence of echolalia can be used to gauge a child’s level of appropriate communication. Children who present with a high proportion of echolalia are likely to suffer from poor comprehension, whereas children who present with a low proportion of echolalia are likely to produce more appropriate language for their age (Roberts, 1989).

In addition to echolalia, morphosyntactic errors, semantic constraint violations, and retrieval/organizational difficulties have been found in the language of children with autism (Adams, 1998; Brook &

Bowler, 1992; Eskes, Byson & McCormick, 1990; Oshima-Takane & Baroya, 1989; Roberts, 1989; Spinelli, 1995; Volden & Lord, 1991). Also, irregularities in the use of pronouns, including reversal of *you/me* and incorrect usage of the pronouns *he/she*, have been observed (Doyle & Iland, 2004).

Of those children with autism who do not develop oral speech, approximately 50% remain non-oral throughout their lives (Paul, 1987; Seal & Bonvillian, 1997). Some scholars attribute these speech difficulties to pragmatic deficits – a lack of attunement to the ambient speech environment (Baron-Cohen & Staunton, 1994; Paul, Shriberg, McSweeny, Cicchetti, Klin & Volkmar, 2005; Schoen, Paul & Chawarska, 2011; Shriberg, Paul, Black & van Santen, 2010).

However, Prizant (1996) posits that the success of augmentative and alternative communication (AAC) supports that there are specific underlying motor impairments that impede speech production. Oral apraxia has been identified in children with ASD by Page and Boucher (1998) and Rogers, Bennetto, McEvoy, and Pennington (1996). Similarly, speech-related motor planning and motor programming impairments (verbal apraxia-like features), as well as motor execution impairments (dysarthria-like features), have been found (Prizant, 1996; Seal & Bonvillian, 1997; Boucher, Andrianopoulos, & Velleman, 2007; Boucher, Andrianopoulos,

& Velleman, 2008; Boucher, Andrianopoulos, & Velleman, 2009; Boucher, Andrianopoulos, Velleman & Pecora, 2009; Boucher, Andrianopoulos, Velleman, Pecora, Currier, Vyce, Curro, & Hall, 2010; Boucher, Andrianopoulos, Velleman, Perkins, & Pecora, 2010; Boucher, Pecora, Andrianopoulos, & Velleman, 2009; Boucher, Velleman, & Andrianopoulos, 2008; Marili, 2004; Pecora, 2009; Velleman, Andrianopoulos, Boucher, Perkins, Averback, Currier, Marsello, Lippe, & Van Emmerik, 2010). Therefore, scholars hypothesize that these speech differences in autism reflect motor speech deficits (Boucher, Andrianopoulos, Velleman & colleagues 2007-2010; Prizant, 1996; Seal & Bonvillian, 1997; Szypulski, 2003).

The source of speech delays/disorders and prosodic and vocal atypicalities in children with ASD has vital implications for remediation. It is imperative that these questions of the existence, prevalence, and nature of motor speech and related disorders in autism be resolved and substantiated with empirical evidence in order to define and develop treatment strategies to maximize oral communication in this population.

1.1.1. Motor Impairments in Autism

Evidence of generalized motor impairments in autism supports the hypothesis that speech differences in autism reflect motor speech difficulties. Motor impairments and general motor deficits in individuals with autism spectrum disorders (ASD) are a widely noted and accepted phenomenon (Belmonte, Allen, Beckel-Mitchener, Boulanger, Carper & Webb, 2004; Diamond, 2000; Hardan, Kilpatrick, Keshavan, & Minshew, 2003; Muller, Kleinhans, Kemmotsu, Pierce, & Courchesne, 2003; Muller, Pierce, Ambrose, Allen & Courchesne, 2004; Prizant, Wetherby, Rubin & Laurent, 2003). Furthermore, the related concept of “stereotyped and repetitive motor mannerisms” are possible diagnostic criteria for ASD, according to the DSM-IV (2000, p. 70).

Several researchers have attempted to determine prevalence rates of movement disorders and motor impairments in children with ASD. In Sweden, a movement disorder known as Deficits in Attention, Motor and Perception (DAMP) is known to have a strong comorbidity with ASD (Gillberg, 1999). In a retrospective study of medical records, Ming, Brimacombe and Wagner (2007) identified 51% of individuals with autism displaying signs of hypotonia, 35% displaying signs of motor apraxia, and 9% displaying signs of gross motor delays. It was further suggested that, as percentages of such impairments decreased as children aged, it is possible that motor deficits improve over time (Ming et al., 2007; Waelvelde, Oostra, Dewitte, Van den Broeck & Jongmans, 2010). A similar overall figure was reached through the works of Sturm, Fernell and Gillberg (2004), who found that 75% of individuals with ASD displayed signs of motor impairments. Velleman, Andrianopoulos, Boucher et al. (2010) purport that the improvement of motor abilities with age are a function of neurodevelopment and neuroplasticity, thus making it more difficult to differentially diagnose motor speech impairments, such as apraxia of speech and dysarthria, in children.

Given that many individuals with ASD exhibit signs of motor impairments, it remains crucial to define and delineate these impairments. In general, individuals with ASD are described as being “clumsy” (Ghaziuddin, Butler, Tsai & Ghaziuddin, 1994; Green, Baird, Barnett, Henderson, Huber & Henderson, 2002; Thede & Coolidge, 2007) and “uncoordinated” (Allen, Müller, & Courchesne, 2004; Ghaziuddin, Butler, Tsai & Ghaziuddin, 1994). The exact nature of these impairments and the differences that contribute to marked clumsiness and incoordination, however, remain an area of debate among researchers.

Two meta-analyses regarding motor impairments in individuals with ASD have been completed. In one meta-analysis, Fournier, Hass, Naik, Lodha, and Cauraugh (2010) noted that although inconsistent results have been reported, there remains a pronounced pattern of motor impairments amongst individuals with ASD. In a similar meta-analysis, Frazier and Hardan (2009) pinpointed the impairments to be noted primarily during function and imitation of motor movements. These results, nevertheless, remain quite broad due to the differences in methodologies and findings that exist across studies.

Several studies have suggested that imitation is an area of deficit for those with ASD (Dawson, Meltzoff, Osterling, & Rinaldi, 1998; Jones & Prior, 1985) and it has also been suggested that different types of motor imitation exist and may be impacted in various ways (McDuffie, Turner, Stone, Yoder, Wolery & Ulman, 2007). In contrast, other studies have posited that a broader viewpoint of motor impairment is more appropriate in that a general praxis deficit that is not imitation-specific exists (Mostofsky, Dubey, Jerath, Jansiewicz, Goldberg & Denckla, 2006; Zachor, Ilanit, & Itzchak, 2010). Although their research did not investigate the role of imitation, others also believe that more general impairments in motor dysfunction (Enticott, Bradshaw, Iansek, Tonge, & Rinehart, 2009) and praxis (Qiu, Adler, Crocetti, Miller, & Mostofsky, 2010) are more descriptive of the deficits seen in ASD.

Various aspects contributing to motor performance and motor impairments, beyond imitation, have also been investigated. Thus far, more variability than consistency in findings exists within the published literature. Two studies have replicated findings that suggest impaired acquisition of motor movements (Gidley Larson, Bastian, Donchin, Shadmehr, & Mostofsky, 2008; Gidley Larson & Mostofsky, 2008) may be one important factor impacting motor development. On the other hand, impairments in transferring motor control across modalities, i.e., auditory, visual and motor (Nydén, Carlsson, Carlsson, & Gillberg, 2004), or impairments in the ability to sustain motor movements, known as motor persistence (Mahone, Powell, Loftis, Goldberg, Denckla & Mostofsky, 2006) may also contribute to motor differences. Deficits with motor persistence point to increased right hemisphere deficits (Mahone et al., 2006).

A small subset of researchers have attempted to differentiate motor impairments between two groups of children with ASD- those with High Functioning Autism (HFA), and those with Asperger's Syndrome (AS)- with mixed results. Findings suggest that individuals with AS present with a motor clumsiness, while individuals with HFA present with abnormal posturing (Rinehart, Bellgrove, Tonge, Brereton, Howells-Rankin & Bradshaw, 2006). Comparing different participant demographics, immature mirror image imitations were found to be an area of deficit for individuals with high functioning ASD, while a less mature imaginary grip may be a differentiating motor feature of low functioning ASD (Vanvuchelen, Roeyers, & De Weerdt, 2007). Cognitive levels were also suggested to contribute to motor impairments (Zingerevich, Greiss-Hess, Lemons-Chitwood, Harris, Hessl, Cook & Hagerman, 2009); however, differences in IQ are not always stringent differences between diagnoses of HFA and AS and, as such, may contribute to the mixed results between researchers.

Similar correlational findings were also suggested by Dziuk, Larson, Apostu, Mahone, Denckla and Mostofsky (2007), who determined that poorer praxis scores might be predictors of more profoundly impaired features of ASD. While Zingerevich et al. (2009) detailed IQ to motor correlations, Kopp, Beckung and Gillberg (2010) hypothesized that motor coordination could be predicted by age of first motor difficulties, severity of symptoms, and low IQ. Despite differences in correlational components, it appears that motor impairments are related to lower IQ and increased severity of ASD, overall.

As previously noted, motor impairments may improve over time, possibly due to therapeutic interventions. Thus, it seems plausible that such impairments may be present early in life, possibly beginning in infancy. Through retrospective studies of home videos, and other methods, researchers have been able to delve into this area. Consistent findings across studies have revealed that children with ASD experienced delayed milestones (Iverson & Wozniak, 2007), resulting in atypical or impaired motor development (Mostofsky, Powell, Simmonds, Goldberg, Caffo & Pekar, 2009; Noterdaeme, Mildenberger, Minow, & Amorosa, 2002; Provost, Heimerl, & Lopez, 2007; Provost, Lopez, & Heimerl, 2007). Specifically, Teitelbaum, Teitelbaum, Nye, Fryman, and Maurer (1998) localized these differences to occur mainly on the right sides of infants’ bodies. This suggests that the right side may more delayed.

Attainment of walking may be a particularly important motor milestone of interest. When infants who were later diagnosed with ASD began walking, they displayed an increased variability in their walking patterns, as well as employing atypical gait patterns (Esposito & Venuti, 2008). Despite these observed differences, Ozonoff, Young, Goldring, Greiss-Hess, Herrera, Steele, Macari, Hepbrun and Rogers (2008) believe that although motor milestones are delayed in individuals with ASD, these early differences are not helpful in the early identification of ASD.

Walking appears to be an area of atypical performance among children with ASD that continues well beyond the early developmental years. One researcher compared gait and postural abnormalities of children with ASD and found them to be similar to those observed in people with cerebellar ataxia (Rinehart, Tonge, Bradshaw, Iansek, Enticott & McGinley, 2006). Gait was characterized as being uncoordinated, lacking in motor smoothness, and presenting with an increase in stride length. Furthermore, increased speed while walking was noted to produce increased dysrhythmias (Jansiewicz, Goldberg, Newschagger, Denckla, Landa & Mostofsky, 2006). Individuals with ASD need not be engaged in movement to display motor difficulty, though. Impaired balance, including a tendency for young children to fall more often, has been found (Iwanaga, Kawasaki, & Tsuchida, 2000; Jansiewicz, Goldberg, Newschaffer, Denckla, Landa & Mostofsky, 2006).

Additional areas of impairments were found in two unique studies of motor performance focused on hand movements. Fuentes, Mostofsky and Bastian (2009) found that individuals with ASD tend to produce poorer, more illegible handwriting. While observing adolescents with ASD who communicate through sign language, Seal and Bonvillian (1997) found these children to display signs of apraxia, as indicated by poorly developed motor skills and an inability to program transitions across movements, even though these skills are of essence to communicate through sign.

Various viewpoints exist about the etiologies of the motor impairments described above. Individuals with ASD may experience impaired motor perception (Puzzo, Cooper, Vetter, Russo & Fitzgerald, 2009), particularly in their ability to read motor intentions from gaze (Becchio, Pierno, Mari, Lusher & Castiello, 2007). It is also plausible that selected individuals with ASD may experience deficits in the inhibition of motor selection processes (Ciesielski & Knight, 1994).

Very few studies contradict the above findings to suggest that motor impairments do not exist in ASD. However, Morin and Reid (1985) believe that differences in motor execution are more qualitative than quantitative in nature, and are indicative of lowered IQ. This hypothesis is not atypical in that one can expect that the lower an individual’s IQ, the more their central nervous system is affected by neurodevelopmental problems involving cognition, speech, and language functions. Furthermore, Travers, Klinger, Mussey and Klinger (2010) detailed findings from a serial reaction time task in opposition to those of Gidley Larson and Mostofsky (2008), stating that individuals with ASD learn motor movements without conscious awareness and thus, are similar to their neurotypically developing peers.

1.1.2. Motor Speech Characteristics of Autism

There are published studies that support generalized motor impairments in ASD, yet there is little to no agreement across studies. Even less is known and agreed upon within the area of speech-related motor impairments. Fewer than two-dozen published journal articles investigate motor speech differences in autism. However, given the evidence to support generalized motor impairments among individuals with ASD, it seems plausible that motor impairments would also affect speech and oral communication in these individuals (of Adams, 1998; Boucher, Andrianopoulos & Velleman, 2007-2010).

To date, there is limited published research and empirical evidence to support the hypothesis of motor speech impairments in individuals with ASD. It is plausible that a subset of children with ASD have motor speech disorders. Gernsbacher, Sauer, Geye, Schweigert and Hill Goldsmith (2008) found that a subgroup of 15% of infants with ASD exhibited signs and symptoms of an apraxia-like motor speech disorder. In a small study of children with ASD, Sheehy (2008) found both inconsistent trends or signs of an apraxia of speech to be present as well as consistent trends of signs of a dysarthria among children with ASD.

Although he did not make any definitive statements regarding the presence of apraxia or dysarthria, Diehl and Paul (2011) identified motor problems resulting in atypical speech durations, which may also affect DDKs, in children with ASD. Similarly, Gernsbacher, Goldsmith, O'Reilly, Sauer, DeRuyter and Blanc (2002) demonstrated that delayed oral motor skills are a feature of ASD.

Speech motor deficits in children with ASD may be one aspect of their generalized motor impairments (Bonneh, Levanon, Dean-Pardo, Lossos, & Adini, 2010). It is plausible that an underlying neurologic problem may affect both the central nervous system and/or the peripheral nervous system, with impacts on motor speech processes. An underlying genetic component affecting the integrity of the central and peripheral nervous system is also plausible as noted by Flax (Flax, Hare, Azaro, Vieland, & Brzustowicz, 2010).

In conclusion, children with ASD do experience motor speech related deficits, although the exact nature and underlying mechanisms of these deficits remain a contentious topic. Given its importance and relevance to the field of Speech-Language Pathology, researchers need to investigate the presence of motor speech disorders in ASD. A better understanding and identification of the systemic effects of a generalized motor impairment and possibly, a specific speech motor impairment, will assist SLPs to not only differentially diagnoses motor speech impairments, but to better target intervention strategies for their clients with ASD.

1.1.2.1. Prosody

Prosody plays an important role in communication, and can be used to convey emotional content, stress important information, and differentiate language functions, e.g., questions versus statements. A growing body of research supports the hypothesis that both receptive and expressive prosody are impacted in individuals with ASD. Possible underlying mechanisms for these difficulties, however, are mentioned in few articles. Suggested areas of sources of impairment include neurological, cognitive, motoric, linguistic, social, and developmental deficits.

With regard to neurological findings, atypical activation patterns in the left supra-marginal gyrus during prosodic processing have been suggested (Hesling, Dilharreguy, Peppe, Amirault, Bouvard & Allard, 2010). Additionally, prosody has been demonstrated to be used in an apparently random fashion, which when combined with receptive prosodic difficulties involving interpretations of communicative intentions suggests that the right hemisphere may be processing information in an atypical manner (Sabbagh, 1999).

Difficulties have also been found with cognitive aspects of prosody. In one study, participants with ASD were unable to follow the directions for a prosodic elicited production task (Baltaxe, 1984). In a different study, a participant with ASD benefitted from explicit instruction to help them produce prosodic utterances (Bellon-Harn, Harn & Watson, 2011). These studies provide evidence that children with ASD are not cognitively aware of how or why to produce prosody. Furthermore, their cognitive understanding of emotional prosody may be impaired, as evidenced by slowed processing (Malek, 2010).

Difficulties in expressive prosody have pointed to underlying motoric deficits (Noterdaeme, Wriedt & Hohne, 2010). Pecora (2009) found that children with ASD demonstrated increased pitch and variability, along with increased durations. These findings are supported by research conducted by Bonneh, Levanon, Dean-Pardo, Lossos and Adini (2010), who also found larger pitch ranges and more variability. Diehl (2011) details difficulties in producing appropriate durations and in perceiving and imitating prosody; however, misprosodic perceptions were also noted. In contrast, Bellon-Harn, Harn, and Watson (2007) and Bellon-Harn (2011) claim that atypical production of prosody is not due to motor impairments.

Areas of atypical speech production that may reflect motor speech differences include stress and duration. Researchers have reported that children with autism express word and sentence stress atypically (Paul, Augustyn, Kiln & Volkmar, 2005; Shriberg, Paul, McSweeny, Klin, Cohen & Volkmar, 2001), a factor possibly linked to difficulties understanding and processing theory of mind (McCann & Peppé, 2003). Other notable speech differences affect utterance duration and the number and durations of pauses (Zajac, Roberts, Hennon, Harris, Barnes & Misenheimer, 2006). Of particular interest with regard to individuals with autism is the notion that when the said population does not produce prosody in a typical manner, their impaired social and communication abilities are exacerbated or perceived as more severe or impaired (Paul, Shriberg, McSweeny, Cicchetti & Volkmar, 2005).

Although production of prosody obviously involves production of language as well, McCann, Peppé, Gibbon, O'Hare, and Rutherford (2007) believe that levels of accurate prosodic production can be linked to levels of language skills. Similarly, Peppé, Cleland, Gibbon, O'Hare and Castilla (2010) state that prosodic functioning may be related to levels of communicative functioning. Linguistic input may affect prosody as well. Children with ASD may attend to atypical linguistic features (Ploog, Banerjee, & Brooks, 2009), which then impact their perceptions and productions of prosody.

One research group suggested that difficulties with auditory discrimination might contribute to prosodic deficits (McCann, Peppé, Gibbon, O'Hare, & Rutherford, 2006).

As ASD is most notably a disorder of social communicative functioning, researchers have posited that deficits in this area may affect prosodic output. If children with ASD experience difficulties with social emulation and social imitation, it stands to reason that these deficits may alter their prosody and as a result, it is atypical (Paul, Augustyn, Klin & Volkmar, 2005). In addition, students who experience difficulties with interpretation of pragmatic situations may extend these difficulties to their interpretation of prosody (Wilson & Wharton, 2006).

One further area of suggested underlying deficit remains within the realm of delayed prosodic development. Although the above hypotheses point to deviant prosodic development due to deficits in specific underlying mechanisms, some researchers believe that prosody is not deviant, but delayed for children with ASD. Some studies of infants and young children with ASD (Sheinkopf, Mundy, Oller, & Steffens, 2000; Sharda, Subhadra, Sahay, Nagaraja, Singh, Mishra & Singh, 2010) found that vocal patterns were indicative of delayed prosodic development.

Whatever the underlying mechanisms for atypical prosody may be for those on the autism spectrum, both receptive and expressive prosody are atypical for these individuals. Very few studies investigate these proposed breakdowns in a clear and concise manner. There is a need for studies that are designed specifically to investigate possible hypotheses regarding the underlying mechanisms of the prosodic deficits as displayed by individuals with ASD.

1.1.3. Neurological Findings

A large field of research does exist regarding possible neurological breakdowns responsible for ASD, few of which specifically address prosodic deficits. These studies have utilized various neuroimaging techniques, such as magnetic resonance imaging (MRI) and functional magnetic resonance imaging (fMRI). However, the findings across studies are often contradictory of each other and reflect differences in participant demographics with respect to the diagnosis of an ASD and IQ levels, to name some.

The cerebellum is an often-cited area of breakdown for individuals with ASD, perhaps due to its key functions of contributing to the coordination, timing and precision of motor movements, along with fine-tuning of motor activity using inputs from the sensory system and feed-forward and feedback systems. Indeed, increased cerebellar activation during motor performance in individuals with ASD has been found (Belmonte, Allen, Beckel-Mitchener, Boulanger, Carper & Webb, 2004; Diamond, 2000; Hardan, Kilpatrick, Keshavan, & Minshew, 2003; Ornitz, 1974; Rinehart, Tonge, Bradshaw, Iansek, Enticott & McGinley 2006). Allen and Courchesne (2004) further delineated that the ipsilateral anterior cerebellar hemisphere experienced increased activation during motor tasks, along with atypical activation found in the contralateral and posterior cerebellar regions. Contradictory findings from Mostofsky et al. (2009) suggest that cerebellum activation is decreased.

The cerebellum is known to play a contributing role in the coordination, timing and precision of movements, as well as other cognitive-linguistic processes, such as reading. It also aids in the fine-tuning of motor activity utilizing information from the sensory systems (Bhatnagar, 2008). The cerebellum also plays a role in feed forward and feedback (Bhatnagar, 2008). Infarcts to the cerebellum result in ataxic dysarthria. Some researchers support the Cerebellar Deficit Theory as one underlying problem in developmental dyslexia (Fawcett & Nicolson, 2003; Fawcett, Nicolson & Maclagan, 2001; Nicolson, Fawcett, Berry, Jenkins, Dean & Brooks, 1999; Nicolson, Fawcett & Dean, 2001; Nicolson & Fawcett, 2005)

Anatomically speaking, hypoplasia of the cerebellum may exist in those with ASD according to some (Courchesne, 1997; Harris, Courchesne, Townsend, Carper & Lord, 1999; Pierce & Courchesne, 2001). Although its size may be smaller, the cerebellum may demonstrate an increased number of neurons due to impaired neural pruning (Barnea-Goraly, Kwon, Menon, Eliez, Lotspeich & Reiss, 2004). In contrast, surrounding areas of gray matter have been found to be decreased (Rojas, Peterson, Winterrowd, Reite, Rogers & Tregellas, 2006). Impaired neural circuitry has been implicated between the cerebellum and cerebral areas

(Skoyles, 2002), in particular, the frontal lobe (Mostofsky et al., 2009). If excess neural circuitry or impaired neural interconnectivity exist, the efficiency of the neurologic sensori-motor system in individuals with ASD would be decreased.

Increased numbers of pyramidal cells have also been found in the cerebellum (Courchesne, 1997). Pyramidal cells comprise the pyramidal system and are responsible for innervation of motor movements as well as integrating systems for motor control. The cerebellum has reciprocal interconnectivity with the basal ganglia and cerebral cortex and technically is part of the extrapyramidal system (Duffy, 2005). It is plausible that an increased number of their neuronal cells may decrease efficient activation and may contribute to impaired sensori-motor performance for both fine and gross motor movements of the extremities as well as motor speech production.

Despite published findings supporting an impairment at the cerebellar level, Gidley Larson, Bastian, Donchin, Shadmehr and Mostofsky (2008), and Minshew, Luna and Sweeney (1999) posit that the cerebellum is intact and that other regions of neurological deficits are probably implicated.

Several studies have found that the cerebellar vermis is enlarged among those with an ASD compared to their neurotypically developing peers (Akshoomoff, Pierce & Courchesne, 2002; Ciesielski & Knight, 1994). Injury to the cerebellar vermis results in an ataxic dysarthria (motor execution speech impairment). Despite its proposed enlargement, some findings suggest that within the cerebellar vermis, fewer Purkinje cells exist among those with an ASD (Ingram, Peckham, Tisdale, & Rodier, 2000; Yip, Soghomonian & Blatt, 2007). Purkinje cells are the only source of motor output in the cerebellar cortex (Bhatnagar, 2007).

The corpus callosum plays a critical role in connecting the two hemispheres and facilitating inter-hemispheric cortical processing. Given that their participants experienced difficulties transferring motor control across modalities, Nydén, Carlsson, Carlsson, and Gillberg (2004), hypothesized that the corpus callosum may be affected in individuals with ASD. Indeed, imaging studies have found the corpus callosum to be reduced in volume in individuals with ASD (Frazier & Hardan, 2009; Freitag, Luders, Hulst, Narr, Thompson, Toga & Konrad, 2009).

As the cerebellar vermis and the corpus callosum are instrumental in connecting the two cerebral hemispheres and inter-hemispheric processing, impairments in the cerebellar vermis and/or the corpus callosum would impact all modalities of moto-linguistic and other cognitive processes. It is plausible that deficits in the corpus callosum, which imply poor access between the left and right hemispheres, may result in a reduced ability to perceive, interpret and add emotional components to prosody. Additionally, it has been suggested that deficits in the corpus callosum can also result in ideomotor apraxia, as lesions in this area prevent motor information from traveling from the left to the right hemisphere (Bhatnagar, 2013).

The Purkinje cells in this area play a critical role in proprioception. If an individual has fewer Purkinje cells in the cerebellar vermis, they may be less able to identify the position of their body in space. One can speculate that this could result in a decrease in the individuals’ ability to identify where their articulators are making contact during speech acts and in other sensori-motor abilities related to speech production.

On a cortical level, the frontal lobe is an additional area of interest, particularly for speech acts in ASD, as it is known to help suppress unacceptable social responses, a known area of difficulty for many people with ASD.

Researchers have found increased volume in the frontal lobe region (Hardan, Kilpatrick, Keshavan & Minshew, 2003; Pierce & Courchesne, 2001). Causes for this increased volume appear to be unknown to date. It is plausible that neural pruning is impaired or that there is an increase in gray or white matter. Increased gray or white matter volume can contribute to an inefficient neuronal system. These deficits support a possible decrease of functioning in the frontal lobe region and perhaps a decrease in one’s ability to suppress or inhibit unexpected or inappropriate social responses.

In addition, subcortical structures, such as the basal ganglia, have also been reported to underlie communication challenges in individuals with an ASD. The basal ganglia serve many functions, particularly to aid with the initiation, precision, timing, and duration of voluntary and involuntary motor control. The basal ganglia are believed to also play a role in storing and activating a set of macros for overlearned and more automatic motor acts, thus increasing the speed and efficiency in carrying out these sensori-motor processes with minimal conscious effort. Generalized deficits of the basal ganglia have been proposed in numerous studies investigating motor abnormalities in ASD (Enticott, Bradshaw, Iansek, Tonge, &

Rinehart, 2009; Fournier, Hass, Naik, Lodha, & Cauraugh, 2010; Goldberg, Lasker, Zee, Garth, Tien & Landa, 2002; Rinehart Bellgrove, Tonge, Brereton, Howells-Rankin & Bradshaw, 2006; Rinehart, Tonge, Bradshaw, Iansek, Enticott & McGinley, 2006). One investigation correlated the size of the basal ganglia to scores on the Repetitive Behavior domain of the *Autism Diagnostic Interview* (Lewis, Tanimura, Lee & Bodfish, 2007). Proposed atypicalities of the basal ganglia suggest impairment in voluntary motor control. Motor-speech processes can affect one's ability to speak in a voluntary manner, which can be empirically measured as an increase in the latency time between task directions and the initiation of speech.

It is difficult to differentiate and study specific differences within the basal ganglia networks. However, Qiu, Adler, Crocetti, Miller, and Mostofsky (2010) investigated shape abnormalities that were also related to poor praxis and motor skills. It is also possible that white matter volumes may be increased within the basal ganglia (McAlonan, Cheung, Cheung, Wong, Suckling & Chua, 2009) among individuals with an ASD. In contrast, however, one study reported no distinct differences between the basal ganglia of individuals with ASD and individuals who are neurotypically developing (NTD) (Hardan, Kilpatrick, Keshavan & Minshew, 2003).

Although the basal ganglia have been studied to some extent, the supplementary motor cortex and the premotor cortex have received little attention within neuroimaging studies of individuals with ASD. In an EEG study, Enticott, Bradshaw, Iansek, Tonge and Rinehart (2009) found increased activation in the supplementary motor area. This finding was supported through an anatomic MRI study (Mostofsky, Burgess, & Gidley Larson, 2007). Although no neuroimaging was employed, Becchio, Pierno, Mari, Lusher, and Castiello (2007) posited that the premotor cortex may be implicated in poor motor performance among individuals with ASD.

Adjacent to the primary motor cortex is the primary sensory cortex. Bhatnagar (2013) suggests that 40% of motor fibers arise from both this area and the somatosensory association cortex. The sensory system in the brain may activate prior to activation of the motor system and continues to remain active for the duration of the motor action. It is important to acknowledge that motor speech processes are in reality, sensorimotor in nature.

Moving beyond specific neuroanatomical and neurophysiological regions, both gray and white matter, along with mirror neurons, have received much attention in past years. Much of this information, however, has not yet reached a level of consensus amongst researchers and neurologists.

With respect to gray matter, which facilitates sensori-motor control for speech purposes, researchers have hypothesized that there is both a decrease and an increase of gray matter in individuals with an ASD compared to those diagnosed with Asperger Syndrome (AS). It is important to note that an increase in white matter volume, which causes an inefficient neurological system, has been found to predict decreased motor performance (Mostofsky, Burgess & Gidley Larson, 2007). The differences regarding a decrease or an increase of gray matter are possibly due to varying methodologies used to select participants, such as diagnostic and IQ differences. Hadjikhani, Joseph, Snyder, and Tager-Flusberg (2006) and McAlonan, Suckling, Wong, Cheung, Lienenkaemper, Cheung and Chua (2008) found decreased gray matter in individuals with HFA. Similar results were found by Allen and Courchesne (2003) for a group of participants with forms of ASD other than AS. Differences in diagnostic inclusionary/exclusionary criteria may be a factor in the various findings (Akshoomoff, Pierce & Courchesne, 2002; Freitag, Luders, Hulst, Narr, Thompson, Toga & Konrad, 2009; Hepburn & Stone, 2006; Rojas, Peterson, Winterrowd, Reite, Rogers &

Tregellas, 2006). Interestingly, Carper, Moses, Tigue, and Courchesne (2002) found that gray matter volumes were slow to mature across ages in children with ASD as compared to their NTD peers. The underlying cause(s) for these differences in gray matter growth is currently unknown.

Unlike gray matter differences, all studies investigating white matter volume found an increase in individuals with an ASD (Akshoomoff et al., 2002; Barnea-Goraly, Kwon, Menon, Eliez, Lotspeich & Reiss, 2004; Carper & Courchesne, 2005; Freitag et al., 2009; Hepburn & Stone, 2006; Herbert, Zeigler, Makris, Filipek, Kemper, Normandin & Caviness, 2004). McAlonan et al. (2009) reported an increase of basal ganglia white matter in the brain of individuals with HFA, while an increase of white matter in the right hemisphere was more common in individuals with AS.

Similar patterns and mixed findings have been reported regarding mirror neurons. Some researchers maintain that the mirror neuron system in individuals with ASD is decreased or dysfunctional (Dapretto, Davies, Pfeifer, Scott, Sigman, Bookheimer & Jacoboni, 2005; Frazier & Hardan, 2009; Hadjikhani, Joseph, Snyder & Tager-Flusberg, 2006; Vanvuchelen, Roeyers, & De Weerdt, 2007; Villalobos, Mizuno, Dahl, Kemmotsu, & Muller, 2005). This is speculated to be the cause of early developmental failures (Williams, Whiten, Suddendorf, & Perrett, 2001). Other researchers posit that the mirror neuron systems of individuals with ASD are very similar to those of their NTD peers (Dinstein, Thomas, Humphreys, Minshew, Behrmann & Heeger, 2010; Gowen, Stanley, & Miall, 2008). Generalized, dysfunctional mirror neurons have also been suggested (Oberman & Ramachandran, 2007; Oberman, Hubbard, McCleery, Altschuler, Ramachandran & Pineda, 2005; Puzzo, Cooper, Vetter, Russo, & Fitzgerald, 2009; Rogers, 2007).

Impairments in the mirror neuron systems are highly speculative at this time. It is plausible that different subtypes of mirror neurons (e.g., those in different regions of the motor cortex), may be affected in different manners. Additional research is necessary to better define the contributions and differences of these neurons and the effect they have on neurodevelopmental disorders.

The current body of published research suggests that there is a lack of consensus regarding which areas of the brain are impacted in children with autism. The following points summarize these findings:

- Increased volume in the frontal lobe has been replicated across two studies (Hardan, Kilpatrick, Keshavan & Minshew, 2003; Pierce & Courchesne, 2001).

- Increased activation of the motor cortex was found in one study (Enticott, Bradshaw, Iansek, Tonge and Rinehart, 2009).
- The cerebellum has been demonstrated to have decreased activation across five studies (Belmonte, Allen, Beckel-Mitchener, Boulanger, Carper & Webb, 2004; Diamond, 2000; Hardan, Kilpatrick, Keshavan, & Minshew, 2003; Ornitz, 1974; Rinehart et al., 2006b); increased activation in one study (Mostofsky et al., 2009); hypoplasia was replicated in three studies (Courchesne, 1997; Harris, Courchesne, & Townsend, 1999; Pierce & Courchesne, 2001); impaired neural pruning was demonstrated in two studies (Mostofsky et al., 2009; Skoyles, 2002); another study found increased pyramidal cells(Courchesne, 1997), while two other studies posited that the cerebellum was intact (Gidley Larson, Bastian, Donchin, Shadmehr & Mostofsky, 2008; Minshew, Luna & Sweeney. 1999).
- Reduced volume in the corpus callosum was demonstrated in two studies (Frazier & Hardan, 2009; Freitag, Luders, Hulst, Narr, Thompson, Toga & Konrad, 2009).
- Four studies determined that generalized deficits in the basal ganglia existed (Enticott, Bradshaw, Iansek, Tonge, & Rinehart, 2009; Fournier, Hass, Naik, Lodha,

& Cauraugh, 2010; Goldberg, Lasker, Zee, Garth, Tien & Landa, 2002; Rinehart et al., 2006a,b), while one study found white matter to be increased (McAlonan, Cheung, Cheung, Wong, Suckling & Chua, 2009), and another believed that the basal ganglia were intact (Hardan, Kilpatrick, Keshavan & Minshew, 2003).

- Gray matter may be decreased (Hadjikhani, Joseph, Snyder, & Tager-Flusberg, 2006; McAlonan, Suckling, & Wong, 2008), increased (Mostofsky, Burgess & Gidley Larson, 2007, or slow to mature (Carper, Moses, Tigue & Courchesne, 2002).
- Six studies concur that white matter is increased (Akshoomoff et al., 2002; Barnea-Goraly, Kwon, Menon, Eliez, Lotspeich & Reiss, 2004; Carper & Courchesne, 2005; Freitag et al., 2009; Hepburn & Stone, 2006; Herbert, Zeigler, Makris, Filipek, Kemper, Normandin & Caviness, 2004), with no opposing evidence.
- Lastly, mirror neurons have been shown to be decreased or dysfunctional across five studies (Dapretto, Davies, Pfeifer, Scott, Sigman, Bookheimer & Jacoboni, 2005; Frazier & Hardan, 2009; Hadjikhani, Joseph, Snyder & Tager-Flusberg, 2006; Vanvuchelen, Roeyers, & De Weerdt, 2007; Villalobos, Mizuno, Dahl, Kemmotsu, & Muller, 2005); generalized deficits were found within

four studies (Oberman & Ramachandran, 2007; Oberman, Hubbard, McCleery, Altschuler, Ramachandran & Pineda, 2005; Puzzo, Cooper, Vetter, Russo, & Fitzgerald, 2009; Rogers, 2007), and no deficits were demonstrated within two studies (Dinstein, Thomas, Humphreys, Minshew, Behrmann & Heeger, 2010; Gowen, Stanley, & Miall, 2008).

To date, it is difficult to draw conclusions across studies given the broad methodological differences, such as variations across IQ levels and diagnostic criteria of those participants studied on the autism spectrum. Nevertheless, the culmination of research published to date suggests that there are apparent neuroanatomical differences and that one or more areas of the brain may be implicated in ASD. As such, it is logical to conclude that autism is a neurodevelopmental condition and affects underlying neurological components.

1.2. Acoustic Analysis of Speech

One method to investigate motor speech and vocal differences in individuals on the autism spectrum involves the acoustic analysis of speech. This method allows for a more objective measurement of the vocal characteristics accompanying many motor speech disorders. One important reason for utilizing acoustic measures to analyze speech is the fact that they provide a more quantitative method to measure vocal production and sensori-motor activity for speech purposes (Crary & Towne, 1984). The acoustic quality of speech plays a large role in listeners' perceptions of speech. If a listener does not perceive acoustic (speech and language) information that coincides with the speaker's other modes of communication expression, such as body language or facial expression, the acoustic information might be abandoned (Ansel, 1992).

One measure to quantify the features of speech is the duration of the acoustic signal. For example, maximum phonation time (MPT) is the maximum length of time that a client can sustain a speech sound (Haynes & Pindzola, 2004). Sustained vowels, especially [ɑ] and [i], are predominantly used to measure MPT (Titze, 1995). Vowels such as these require a stable vocal performance but do not place large demands on the vocal tract. Thus, performing acoustic analyses of prolonged vowels allows the clinician to assess the function of the larynx (Kent & Kim, 2003; Titze, 1995).

For the vowel [ɑ], a neurotypical child between six and ten years of age usually can produce a MPT of 9 seconds (Haynes & Pindzola, 2004; Kent, Kent & Rosenbek, 1987). MPT has been determined to have diagnostic value with relation to motor-speech behavior regarding respiratory efficiency and demands for speech purposes (Maassen, Nijland & Van der Meulen, 2001). Children with ASD have been shown to produce abnormally short MPTs (Boucher, Andrianopoulos, & Velleman et al., 2007-2010; Marili, 2004; Pecora, 2009).

Another quantifiable parameter of the acoustic signal is fundamental frequency. The vocal fold vibration that occurs during the production of speech sounds is shaped into a series of sound frequencies that can help the listener to differentiate among these sounds (Mullin, Gerace, Mestre & Velleman, 2003). The fundamental frequency correlates to the pitch of a person's voice, and in part, is dependent upon the length and thickness of the vocal folds (Roth & Worthington, 2005). Typically, a male child between the ages of five and eight years old is expected to have a fundamental frequency of 250-265 Hertz (Hz), whereas a female child of the same age is expected to have a fundamental frequency between approximately 255-265 Hz (Baken & Orlikoff, 2000; Roth & Worthington, 2005).

Titze (1995) examined two other measures of speech acoustics: shimmer and jitter. Both of these measurements are cycle-to-cycle perturbations, or cyclic instabilities or aperiodicities, of the acoustic signal during phonation.

Shimmer is a measurement of the degree of amplitude perturbation and jitter is a measurement of frequency perturbation in the acoustic signal one produces during vowel prolongation. It has been further noted that both jitter and shimmer differ depending upon fundamental frequency, intensity, and vowel selection (Gelfer, 1995).

Both jitter and shimmer have clinical utility for predicting and differentiating between different types of vocal pathologies and level of severity, providing that one controls the quality of the acoustic recording and the manner and methods for analyzing the speech sample (Bough, 1996; Titze, 1995). Normative data suggests that Jitter Percent for children age 4;0-10;2 should be 1.551% for the vowel [a], and 1.113 for the vowel [i]. Similarly, Shimmer in dB values for the vowel [a] remain at 0.610 dB, and at 0.465 dB for the vowel [i] (Wertzer, Schreiber & Amaro, 2005).

Vowels are formed as the fundamental frequency is shaped by the configuration of the vocal tract, yielding a series of resonances, or formants. For children, the first three formants of the vowel [a] would be expected to be approximately 1030 Hz, 1370 Hz and 3170 Hz, with similar values of 370 Hz, 3200 Hz and 3730 Hz for the vowel [i] (Peterson & Barney, 1952).

Vowel distortions occur frequently within children with ASD (Boucher, Andrianopoulos & Velleman 2007-2010). Through acoustic analyses, it is possible to better define the nature of these distortions. Andrianopoulos (2001a) further explains that the varying acoustic qualities are a result of an individual's oral cavity, vocal tract, and general anatomy of the speech mechanism. Characteristics of the production of speech sounds (e.g., vowels such as [ɑ], [u], and [i]) and connected speech can also differ depending upon a person's race, culture, and gender (Andrianopoulos, 2001b).

The second formant, or F_2, has been demonstrated to be especially salient in listeners' perception of speech. This formant, in addition to the first formant, provides much information both from a psychoacoustic and a linguistic perspective (Bunton & Weismer, 2001; Weismer & Martin, 1992). That is to say, these two formants determine which vowel a listener perceives based upon the acoustic properties of the speaker's voice.

Boucher, Andrianopoulos, Velleman et al. (2007) have demonstrated formant values to be increased for children with ASD, while Perkins et al. (2008) found decreased formant values.

Besides vowels, the other category of sounds, or phones, present within the English language is consonants. Consonants are differentiated from one another by approximately three characteristics: their voicing (voiced or voiceless), manner of articulation (stop, nasal, fricative, etc.), and place of articulation (labial, alveolar ridge, velum, etc.) (Small, 1999). Consonants can also be measured directly through acoustic analysis of speech as can their effect on surrounding vowels in connected speech.

Factors such as pitch, duration, vocal quality, and loudness serve additional functions when they are combined. For example, when a word is stressed in English it should be marked by a longer duration, higher pitch, and greater intensity (Small, 1999). Neurotypically developing children as young as 18 months of age are able to consciously control these factors and function similarly to adults (Kehoe & Stoel-Gammon, 1995). If children with autism do not produce appropriate stress and intonation, it is necessary to determine the extent to which they are able to control these features to the degree expected as compared to their peer group within their culture.

Other measures of speech production have also been found to be useful for identifying speech disorders.

Syllable repetitions, such as Automatic Motion Rates (AMRs) & Sequential Motor Rates (SMRs), are largely dependent upon a person’s ability to articulate syllables rapidly and precisely, which requires many stages and processes of sensori-motor programming, planning, and motor execution. One factor upon which these rates are dependent is the ability to program, plan, and execute opening and closing the jaw quickly and with precision using numerous co-articulatory and overlapping ballistic movements and speech processes (i.e., respiration, phonation, articulation, and resonation). Hertrich and Ackermann (2000) noted that there is a largely inconsistent pattern of jaw opening across various neurotypically developing individuals; however, the level of speech precision varies even more among those individuals with neurodevelopmental as well as speech and language-related problems.

For example, AMRs are a verbal-sensori-motor task involving repetition of a single syllable, commonly used [pʌ], [tʌ] and [kʌ] (e.g., [pʌ pʌ pʌ pʌ pʌ...]). Similarly, SMRs are also a verbal-sensori-motor task involving the repetition and sequencing of a tri-syllable phrase, such as [pʌtʌkʌ] (Roth, 2005). SMRs (also known as diadochokinetic rate, DDK), are measured in syllables per second and are typically produced in the range of 3.6 to 4.8 syllables per second for neurotypically developing children between six and eight years of age regardless of gender (Fletcher, 1972; Kent, Kent, & Rosenbek, 1987; Perkins, 2006).

Due to the fact that the degree of jaw opening, tongue positioning, and shaping of the vocal tract helps determine the vowel formants, it is plausible that children who have difficulties producing phonation, syllable repetitions, and speech would also have variable formant frequencies. Difficulties in producing age-appropriate diadochokinetic rates have been found in children with childhood apraxia of speech (Williams & Stackhouse, 2000) and children with motor execution problems with respect to speed, precision, and/or duration (Strand & McCauley, 1999; Thoonen, Maasen, Gabreels & Schreuder, 1999). SMRs present a greater challenge for those with CAS, while AMRs present more of a challenge for those with dysarthria (Perkins, 2006; Maasen, Nijland & Van Der Meulen, 2001; Thoonen, Maassen, Gabreels & Schreuder, 1999; Williams & Stackhouse, 2000). Similar difficulties have been found in children with ASD (Boucher, Andrianopoulos, & Velleman, et al., 2007, 2008, 2009, 2010; Marili, 2004; Pecora, 2009).

There are a variety of technologies for acoustic analysis that are either commercially available or in the public domain. One commercially prepared program designed by KayPentax, the Multi-Dimensional Voice Program (MDVP), can analyze speech samples and measure variables such as jitter and shimmer and a host of approximately 28-30 other acoustic parameters of one acoustic signal. While the norms associated with the program reflect norms for adults, Campisi, Tewfik, Manoukian, Schloss, Pelland-Blais, and Sadeghi (2002) created a set of norms, as displayed below, from a study of males and females between 4 and 18 years of age.

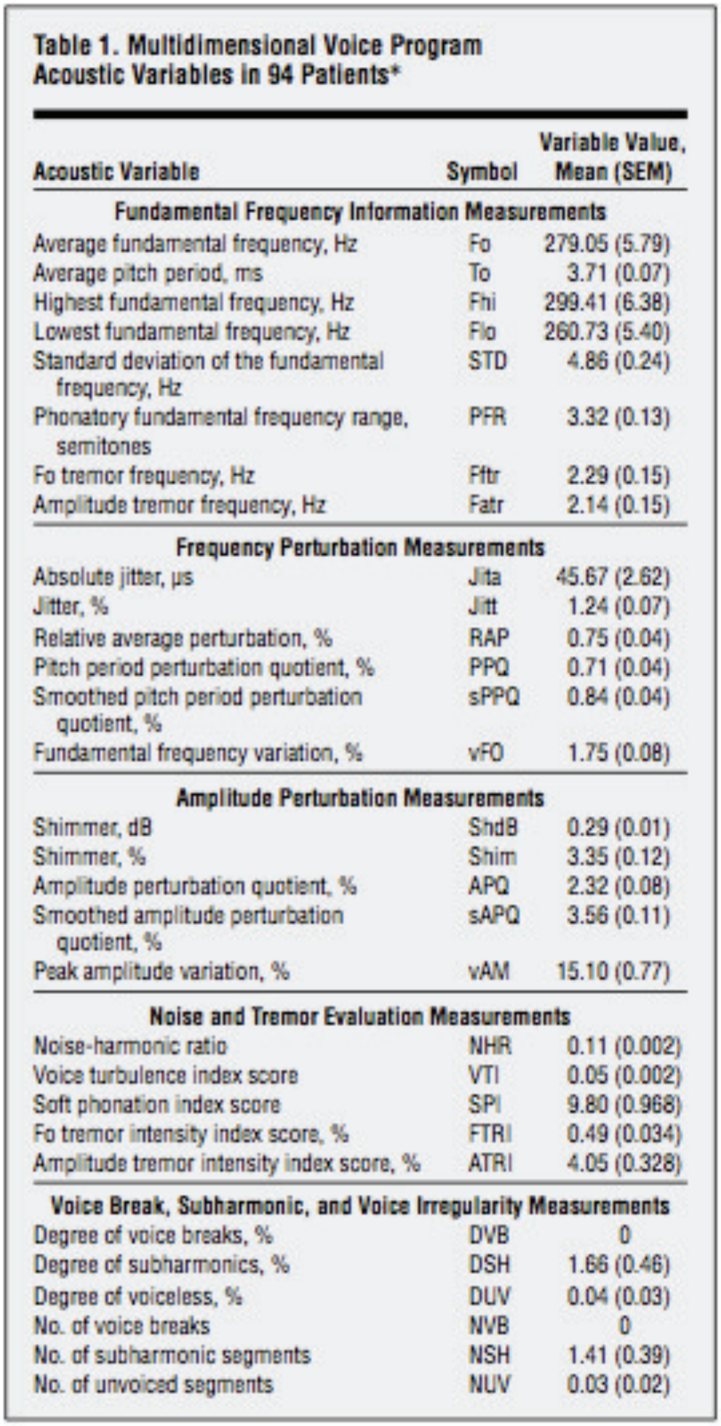


Table 1. Multidimensional Voice Program Acoustic Variables in 94 Patients*

Acoustic Variable	Symbol	Variable Value, Mean (SEM)
Fundamental Frequency Information Measurements		
Average fundamental frequency, Hz	Fo	279.05 (5.79)
Average pitch period, ms	To	3.71 (0.07)
Highest fundamental frequency, Hz	Fhi	299.41 (6.38)
Lowest fundamental frequency, Hz	Flo	260.73 (5.40)
Standard deviation of the fundamental frequency, Hz	STD	4.86 (0.24)
Phonatory fundamental frequency range, semitones	PFR	3.32 (0.13)
Fo tremor frequency, Hz	Fftr	2.29 (0.15)
Amplitude tremor frequency, Hz	Fatr	2.14 (0.15)
Frequency Perturbation Measurements		
Absolute jitter, μs	Jita	45.67 (2.62)
Jitter, %	Jitt	1.24 (0.07)
Relative average perturbation, %	RAP	0.75 (0.04)
Pitch period perturbation quotient, %	PPQ	0.71 (0.04)
Smoothed pitch period perturbation quotient, %	sPPQ	0.84 (0.04)
Fundamental frequency variation, %	vFO	1.75 (0.08)
Amplitude Perturbation Measurements		
Shimmer, dB	ShdB	0.29 (0.01)
Shimmer, %	Shim	3.35 (0.12)
Amplitude perturbation quotient, %	APQ	2.32 (0.08)
Smoothed amplitude perturbation quotient, %	sAPQ	3.56 (0.11)
Peak amplitude variation, %	vAM	15.10 (0.77)
Noise and Tremor Evaluation Measurements		
Noise-harmonic ratio	NHR	0.11 (0.002)
Voice turbulence index score	VTI	0.05 (0.002)
Soft phonation index score	SPI	9.80 (0.968)
Fo tremor intensity index score, %	FTRI	0.49 (0.034)
Amplitude tremor intensity index score, %	ATRI	4.05 (0.328)
Voice Break, Subharmonic, and Voice Irregularity Measurements		
Degree of voice breaks, %	DVB	0
Degree of subharmonics, %	DSH	1.66 (0.46)
Degree of voiceless, %	DUV	0.04 (0.03)
No. of voice breaks	NVB	0
No. of subharmonic segments	NSH	1.41 (0.39)
No. of unvoiced segments	NUV	0.03 (0.02)

(Campisi, Tewfik, Manoukian, Schloss, Pelland-Blais, & Sadeghi, 2002, p. 158)

Typically developing children acquire the acoustic features that resemble the adult model within their culture and race at varying points during their maturation (Robbins & Klee, 1987; Smith & Goffman, 1998). However, the most significant changes noted in pitch or fundamental frequency in both males' and females' voices are during the pubescent period of development.

1.3. Overview of the Study

Children with autism are reported to exhibit motor deficits that impact their everyday functioning, as well as their speech production. It was the aim of this study to identify the presence or absence of specific motor speech markers in autism through an innovative best-practice protocol for assessing the speech, prosody, and vocal quality of individuals with ASD. The study focused on apraxic-like motor programming/planning features and dysarthric-like motor execution features in spontaneous, elicited, and imitated speech. Using acoustic analyses as well as behavioral measures, we empirically demonstrate the existence, prevalence, and nature of speech, phonatory, and prosodic differences or deficits in this population.

1.4. Research Questions

1. Are there specific motor speech features that support probable underlying motor speech impairments, such as apraxia of speech and dysarthria that can differentiate children with ASD from children who are NTD?
   - Null hypothesis: There are no specific motor speech features that support probable underlying motor speech impairments, such as apraxia of speech or dysarthria, that can differentiate children with ASD from children who are NTD.
   - Alternate hypothesis: There are specific motor speech features that support probable underlying motor speech impairments, such as apraxia of speech or dysarthria, that can differentiate children with ASD from children who are NTD.
2. Are there specific perceptual features of speech that judges can reliably and consistently perceive, in order to differentiate the speech of children with ASD from that of children with NTD?
   - Null hypothesis: There are no specific perceptual features of speech that judges can reliably and consistently perceive, in order to differentiate the speech of children with ASD from that of children who are NTD.

- Alternate hypothesis: There are specific perceptual features of speech that judges can reliably and consistently perceive, in order to differentiate the speech of children with ASD from that of children who are NTD.

3. Are there specific acoustic variables that contribute to a listener’s perception of the parameters Overall Severity, Roughness, Breathiness, Strain, Pitch and Loudness?

   - Null Hypothesis: There are no specific acoustic variables that contribute to a listener’s perception of the parameters Overall Severity, Roughness, Breathiness, Strain, Pitch and Loudness.
   - Alternate Hypothesis: There are specific acoustic variables that contribute to a listener’s perception of the parameters Overall Severity, Roughness, Breathiness, Strain, Pitch and Loudness.

CHAPTER 2

METHODOLOGY

2.1. Procedures

Two independent sample groups of equal size participated in the study, using a group comparison design. An a priori power analysis was conducted using the *G*Power3* calculator. Parameters included in the analysis were t-test (means: difference between two independent means), power at 0.8, an alpha of 0.05, and a large effect size of 0.5. Results of the analysis suggested that a sample size of 120 participants would be large enough to detect any group differences, if such differences did exist. It was determined that this number was not feasible to obtain.

2.2. Participants

Two cohorts of participants were included in the study. The first cohort was comprised of fifteen (15) children with an autism spectrum disorder. The second cohort consisted of a control group of fifteen (15) children who were neurotypically developing. Participants were age- and gender-matched to the maximum extent possible.

Parents/guardians were asked to complete and return a short permission form indicating that they were willing to be contacted before being screened over the phone to confirm their child’s eligibility and availability. A set of inclusionary/exclusionary criteria was discussed with the parents/guardians. Information regarding their child’s date of birth, diagnosis, other co-morbid diagnoses, size of oral vocabulary, and presence/absence of uncorrected auditory and visual deficits was obtained.

Participants were recruited through flyers distributed at several local school systems, as well as one private speech and language practice. The school systems of Agawam, South Hadley, and West Springfield, Massachusetts provided a letter of support stating their agreement to distribute these flyers to their students. Additionally, families displayed a strong network of collaboration, and shared the research information among other friends and families who were interested in participating.

All participants met a set of inclusionary and exclusionary criteria, as follows: between the ages of four years and twelve years, eleven months; a minimum vocabulary size of ten oral words; no cranio-facial or other structural deficits (e.g., cleft palate) and no uncorrected hearing or visual deficits (mild hearing loss acceptable).

Additionally, all participants within Cohort 1 met the following criteria: have a definitive diagnosis of an autism spectrum disorder from a qualified medical professional, and have a vocabulary of a minimum of 50 words (oral, signed, or PECS).

Of the participants within cohort 1, eight participants were diagnosed with autism, four participants were diagnosed with PDD-NOS, and three participants were diagnosed with Asperger's syndrome. Two participants with autism had a co-morbid diagnosis, one with Childhood Apraxia of Speech, and the other with generalized motor programming/planning difficulties. A total of two females and thirteen males participated. The mean age was 8 years, 4 months, with a range of 4 years, 5 months to 12 years, 9 months. Cohort 2 was comprised of five females and ten males. The mean age was 8 years, 4 months, with a range of 4 years, 5 months, to 12 years, 7 months. Table 1 contains demographic information.

Once eligibility for the study was determined, parents provided scheduling preferences. At the initial visit, parents/guardians signed a full informed consent form. The participants of the study, i.e., the children, also signed a child consent form, or provided oral assent, whichever was most appropriate for each individual.

Parents/guardians were consulted regarding their child’s preferred method of communication to determine appropriateness. Of the thirty children who participated, 19 provided signed consent, while the remaining 11 provided oral consent. The principal investigator obtained all informed consent.

The University Human Subjects Review Committee approved the study. To further protect the welfare of the participants, the investigator and all collaborators in this study completed an online tutorial and became certified in the Collaborative IRB Training Initiative (CITI), a program concerning the protection of human research subjects.

2.3. Perceptual Judges

A total of twelve (12) second-year students enrolled in the [U.S. Department of Education, OSEP COMBINED PRIORITY (CFDA 84.325K, H325K090328)], Training Speech-Language-Pathologists to Assess and Manage Communication Skills in Children with Autism (Andrianopoulos, Velleman, Zaretsky, Boscardin, & Mercaitis, 2010-2012) at the University of Massachusetts in Amherst] within the Speech and Language Pathology master’s degree program at the University of Massachusetts Amherst served as perceptual judges. Students were trained in a two-hour session led by an expert in voice, following the procedures of Darley, Aronson and Brown (1969a,b, 1975; Stemple, Glaze & Klaben, 2009). By the conclusion of the session, the students were able to reliably and consistently distinguish vocal features of both normal and abnormal adult and pediatric voices. This group was deemed the “novice” group.

A questionnaire was distributed to the novice group of perceptual judges, exploring their previous usage of the CAPE-V, if any, as well as pertinent information. This included musical/voice training, age, gender, area of upbringing, and language(s) spoken. Appendix A contains this history form.

Additionally, four well-seasoned doctoral students with more than five years of experience as speech and language pathologists served as the “expert” group. Two additional judges completed this group, one of whom was a speech language pathologist with expertise in voice and voice disorders, and the other and speech and language pathologist and clinical instructor with greater than 25 years experience. These investigators completed the same, although separate, training session and questionnaire.

All students completed an online tutorial and become certified in the Collaborative IRB Training Initiative (CITI) to ensure protection of human research subjects.

2.4. Tasks

Three levels of speech production were selected for analysis: imitated, elicited and spontaneous speech.

A subset of items from the Verbal Motor Production Assessment (VMPAC) (Hayden & Square, 1999) supplemented by tasks from Smith and Goffman (1998) and Thoonen et al. (1999), were selected to study the acoustic features of imitated speech in the participants. These stimuli include: prolongation of the vowel [a] and the fricative [f]; production of the vowel [i]; repetition of the short phrase “pea, tea, key,” Alternate Motion Rates (AMRs) of the syllables [pʌ], [tʌ] and [kʌ], and Sequential Motor Rates (SMRs) of [pʌtʌkʌ]. Each stimulus was modeled for the child and then the child was prompted to repeat the stimulus three times. These tasks comprised the group of imitated speech tasks.

Elicited speech stimuli included counting from 1-10 and singing the song “Happy Birthday.” Spontaneous speech samples were obtained from the telling of a story based upon the picture stimuli from the Edmunton Narrative Norms

Index (ENNI) by Schneider, Dube and Hayward (2005) and discussing a topic of individual interest. Two stories, story A3- Airplane and B3- Balloon from the ENNI were implemented. These stories were chosen upon recommendation from the authors as having the clearest story structure. Additionally, Story B3 is a more complex story that contains an element of perspective taking. The full protocol and task directions can be found within Appendix B.

It is important to note that not all participants were able to complete the elicited and spontaneous speech tasks. Three participants with ASD presented with insufficient language abilities to complete these tasks. Two participants labeled items in response to clinician prompting, and one participant produced spontaneous, random vocalizations. The *Counting* task was completed by 12 of the 15 participants with ASD. Two additional ASD participants were unable to complete the *Happy Birthday* task due to behavioral issues, e.g., sensitivity around "silliness." Ten of the 15 children with ASD sang *Happy Birthday*. In addition to the three participants with insufficient language abilities, one other child with ASD experienced a behavioral meltdown and would not comply with tasks beyond

Counting; thus for the stories and Topic of Interest tasks, 11 participant samples were obtained from the ASD group.

The NTD group experienced a higher rate of task completion. All participants completed the *Counting* task. Similar to the ASD group, four participants were uncomfortable singing the *Happy Birthday* song. One participant was uncomfortable participating past the *Counting* task; thus, for the Stories and Topic of Interest task, 14 participant samples were obtained from the NTD group.

A cohort of five trained masters' level graduate student clinicians in speech language pathology at the University of Massachusetts in Amherst administered and collected the acoustic and motor speech data from the child participants to control for examiner objectivity. The graduate students were trained in the administration of the protocol, and were deemed by the principal investigator to be reliable and accurate in their judgments. The graduate students were kept blind to the purpose of the study.

2.5. Instrumentation

Acoustic signals were captured and analyzed according to guidelines set forth by the National Center for Voice and Speech (NCVS, Titze, 1995). Analyzable spoken responses were recorded onto a digital flash recorder using the Tascam DR-680 digital recorder. The digital recorder was a valuable and reliable piece of equipment allowing for ease and consistency in collection of data. The AKG C-420 Model head-mounted condenser microphone was placed on each participant’s head situated at a 45° angle, with a one-inch mouth-to-microphone distance. Three participants were unable to wear the head-mounted microphone for the duration of the recording session due to sensory needs; in these cases the principal investigator held the microphone approximately one inch from the mouths of the participants.

All recordings were obtained in a sound-treated, double-wall chamber to minimize ambient noise levels. The recording environment was child appropriate, i.e., a child-sized table and chairs were provided, the room was brightly lit, etc. At the beginning of testing, the microphone was adjusted to allow headroom of 10 dB on the digital recording, and this setting remained constant at this level without adjustment throughout the remainder of testing. Samples were then edited and analyzed using the Multi-Speech (Model 3700) and Multi-Dimensional Voice Profile (Model 5105) programs by Kay Pentax. These computer software programs are designed to analyze speech and produce a set of quantitative measurements for each acoustic signal fed into the software program.

Utilizing the Multi-Speech and MDVP, speech tasks from the digital flash recordings were down-sampled to 11025 Hz. The voice analysis setting from MDVP was utilized to provide acoustic parameters of speech. Other analyses completed within Multi-Speech using segments of the acoustic waveforms included length of utterances (sec), and pauses (sec), as well as maximum phonation time (sec). Table 2 illustrates the measurements taken for each specific speech task. The primary author of this study collected and edited all acoustic samples to ensure consistency in editing of the data.

Once analyzed, all data were saved onto a Microsoft Excel® spreadsheet and additional statistical analyses were performed. One trained undergraduate student and the principal investigator entered all data. Twenty percent of the total data were rechecked for accuracy of data entry into the spreadsheet.

2.6. Perceptual Analysis

Following the acoustic collection and analysis of data, speech samples were randomized and presented for perceptual analysis. Perceptual measures of speech and voice are often implemented to supplement acoustic measures of speech.

In the United States, the Consensus Auditory Perceptual Evaluation of Voice (CAPE-V; American Speech Language Hearing Association Special Interest Division 3 Voice and Voice Disorders, 2006) is the recommended clinician-based measure to subjectively describe speech, permitting SLP clinicians to collect, compare, and describe vocal features in a systematic and standardized manner. Thus, it complements acoustic analysis by efficiently capturing human percepts of the appropriateness of a person’s speech. The CAPE-V provides six parameters to assess speech, measured along a 100-millimeter line. These parameters include: breathiness, roughness, pitch, strain, loudness and overall severity. The CAPE-V has been demonstrated to be a reliable and valid judgment of voice (Zraick, Kempster, Connor, Klaben, Bursac & Glaze, 2011). Hillman (2013) points out the need for a universal perceptual screening tool, and recommends using the CAPE-V with a variety of clients, which may include children with ASD.

The perceptual judges were trained in the methods of Darley, Aronson and Brown to ensure that they would be able to rate voices in an appropriate though subjective manner, based on a set of well-defined and descriptive features. Speech and voice samples were rated using the CAPE-V on one set of randomized samples. Speech samples subjected to the perceptual analyses included counting, singing Happy Birthday, telling two stories, and discussing a topic of interest. The speech samples from the imitated speech stimuli were not included in these analyses as their brief duration was determined to be insufficient to allow for reliable and consistent perceptual analysis. Therefore, the judges only rated the speech samples obtained from the higher functioning children, who may have presented with less severe vocal qualities.

Perceptual raters completed analyses individually, using the following guidelines:

a. Sit approximately one arm's length away from your computer.

b. Sit in front of your computer, so that you are viewing the screen and equally centered in front of your monitor.

c. Listen to the samples through your computer's built in speakers.

d. Do not use headphones or external speakers.

e. Complete these ratings in a quiet, distraction-free setting with very little ambient noise or distractions.

f. You may listen to each sample up to three times, but please do not listen more than three times.

g. Follow the rating procedures that Dr. A. taught during the seminar.

h. Keep in mind that the samples are obtained from children between the ages of 4 and 12 years.

i. Make sure you clearly mark each parameter, measure your marking, and write the numerical value on the appropriate line.

j. It may be helpful to complete these in pencil in case you change your mind after the first or second trial.

2.7. Statistical Methods

Differences and/or similarities between and within groups per variable were analyzed using Excel formulas and the Predictive Analytic Software (PASW, Version 18; SPSS Inc., 2009) statistical programs. Individual data were analyzed first. All acoustic results from the imitated speech tasks sampled were averaged across the three tokens obtained per individual participant. Mean values were calculated using the AVERAGE function within the spreadsheets. Additionally, standard deviations were calculated using the STDEV function to determine the individual’s variability across the task. This measure is referred to as “within-task individual variability.”

Once individual statistical analyses were conducted, group averages and standard deviations were obtained for each task. The group standard deviation of a task is referred to as “within-task group variability.”

A bar graph was created of the acoustic results obtained from the Multi-Speech and MDVP programs to examine them for normal distribution. It was found that three outliers existed: ASD7, ASD8 and ASD9. These participants performed significantly better than their age-matched typical peers on all tasks, including the perceptual analyses. Thus, these three subjects were eliminated from all statistical analyses.

The PASW 18 software program was used for statistical analyses. To investigate between-group differences, the nonparametric statistic Mann-Whitney U was calculated. 12 subjects with ASD and 15 NTD control subjects were included in these analyses. Alpha was set to 0.05 for statistical significance purposes. Effect size was calculated using an Excel effect size spreadsheet, and was derived from the sample size, mean and standard deviation. For ease of reporting, all effect sizes are stated in the absolute value.

Data obtained from the perceptual analyses were first analyzed using Cronbach’s alpha to investigate consistency. As it was the goal of this project to correlate the acoustic measurements to the perceptual ratings, it was first imperative that the perceptual ratings be deemed reliable and accurate. Cronbach's alpha can be used to investigate how reliable a set of data is. Results range from zero to one, with results closer to one representing more reliable and consistent data. In general, an alpha of 0.700 or greater is considered to be acceptable (SPSS FAQs, 2013). This was calculated for both groups of perceptual raters: the Novice Group and the Expert Group. However, the visual inspection of the data, combined with results of the Cronbach's alpha revealed a wide range of consistency (0.350-0.908) within the Novice Group, and thus, these data were deemed unreliable and inconsistent. Data obtained from the Expert Group revealed a higher level of consistency and were maintained for statistical purposes.

Acoustic measurements from the twelve participants with ASD and the 15 neurotypical controls were then correlated to the perceptual analyses from the expert group. A bivariate correlation was implemented. A bivariate correlation can measure the strength between two variables. Values range from zero to one, wherein higher values represent stronger correlations. To be considered a strong correlation, data must have revealed a minimum alpha of 0.700.

CHAPTER 3

RESULTS

The sample population of this study consisted of a total of thirty children comprised of two groups of 15 children. The experimental group included fifteen children with ASD, while the control group consisted of 15 children who were NTD. All participants were children between the ages of four years and twelve years, eleven months. Participants within the NTD group were age- and gender-matched to the ASD group to the maximum extent possible. Table 1 provides a breakdown of the participants by age, gender, and diagnosis.

Statistical comparisons for each independent variable demonstrate differences in the acoustic and perceptual measurements of the children with ASD compared to their NTD peers. As stated previously, three subjects (ASD7, ASD8 and ASD9) were removed from all statistical calculations following visual analysis of the data, which revealed these three subjects to be outliers. Each independent variable is presented below in a task-by-task manner. Specific measurements obtained by task are noted in Table 2.

3.1. Acoustic Results

All acoustic results were obtained from the Multi-Speech and Multi-Dimensional Voice Profile (MDVP) programs from Kay Pentax. Of particular interest were maximum phonation times, total utterance and pause durations, formants, pitch, speech automaticity tasks, and voice measurements.

3.1.1. Maximum Phonation Time (MPT)

Participants with ASD demonstrated decreased maximum phonation times for both the fricative [f] and the vowel [a]. Group statistics for the vowel [a] may be found within Table 3, and group statistics for the phoneme [f] may be found within Table 5. Table 4 details each child's MPT of [f], while Table 6 details [a] MPTs. A visual representation of mean times may be viewed in Figure 1.

As a group, the children with a diagnosis of ASD had significantly shorter productions of [f] than children who were NTD (x_{ASD}=3.11 seconds, x_{NTD}=5.00 seconds). This difference was statistically significant ($p<0.03$, $d>0.70$). Individual participants with ASD were noted to be more consistent across the three tokens obtained than were their NTD peers. This was in contrast to the group variability, which suggested that, as a group, the children with ASD were more variable than the children who were NTD.

Similarly, prolongations for the vowel [a] were shorter for the ASD group (x_{ASD}=4.51 seconds, x_{NTD}=7.32 seconds). This difference was not found to be statistically significant ($p<0.08$, $d>0.62$). Unlike with [f] MPTs, the children who were NTD were more variable than the children with ASD at the individual level. As a group, the ASD cohort was more variable. These data concur with the findings of Boucher, Andrianopoulos, Velleman, et al. and suggest that shortened MPTs are a significant characteristic of speech of children with ASD.

3.1.2. Duration

Previous research (Pecora, 2009) has shown that children with ASD present with increased durations for total utterance length, vowel length, and pause length.

3.1.2.1. “pea tea key”

Total phrase duration for the elicited short phrase “pea tea key” did not result in a statistically significant difference between the two groups ($p<0.64$, $d>0.58$). In spite of the lack of statistical significance, the ASD group produced longer total phrase durations than their NTD peers (x_{ASD}=1.59 seconds, x_{NTD}=1.30 seconds). These results may be viewed in Table 7.

With regard to pause durations, the ASD cohort produced slightly longer pauses for the *pea-tea* gap (x_{ASD}= 0.25s, x_{NTD}=0.23s), while the pauses for the *tea-key* gap was slightly shorter (x_{ASD}= 0.20s, x_{NTD}=0.24s). Neither of the pause differences resulted in statistically significant differences ($p<0.72$, $p<0.64$; $d>0.13$, $d>0.38$ respectively).

Vowel length durations for the [i] of “pea” (x_{ASD}=0.28s, x_{NTD}=0.25s) and *tea* (x_{ASD}=0.26s, x_{NTD}=0.22s) continued the same trend of slightly longer, but not statistically significant differences ($p_{pea}<0.94$, $d>0.30$; $p_{tea}<0.40$, $d>0.37$), for the ASD group. However, for the vowel [i] of the word “key,” the ASD group produced a statistically significant difference ($p<0.00$, $d>1.63$) from the NTD group. This was evident in the increased length of the vowel (x_{ASD}= 0.27s, x_{NTD}=0.16s). It is important to note that all vowels were long and of approximately equal duration regardless of position.

Across all measurements the ASD group was more variable on an individual and group level than the NTD cohort.

3.1.2.2. Counting

Similar trends as those observed on the “pea tea key” task were also noted in the Counting task, as seen in Table 8. Total duration time to count from one to ten for the ASD group was longer than that for the NTD group (x_{ASD}=5.42s, x_{NTD}=4.70s), although this difference was not statistically significant ($p<0.22$ $d>0.35$). Surprisingly, group variability was slightly higher for the NTD group. Mean individual variability was not calculated for this task as only one token was obtained.

A total of nine gap durations were calculated, occurring between each pair of digits. A steady trend of increased pause duration for the ASD group, with increased group variability, can be noted across most durations. The exceptions occur at the gap between 3 and 4, where group variability was the same for both groups, and at the 9 to 10 gap, where the pause duration was the same for both groups.

Pause data were collapsed across all nine data points to obtain average gap data. These data reveal that the ASD group produced longer pauses (x=0.52s) than the NTD group (x=0.23s), with both greater individual variability (SD_{ASD}=1.02, SD_{NTD}=0.25) and greater group variability

(SD_{ASD}=0.95, SD_{NTD}=0.41). Results were not statistically significant ($p<0.22$, $d>0.43$).

3.1.3. Alternate Motion Rates & Sequential Motor Rates

When calculating rate of production in syllables per second, no statistically significant differences between the ASD and NTD groups were found. This was in accordance with previous findings by these investigators. Results, detailed in Table 9, revealed that syllable per second rates for [pʌ] (x_{ASD}=4.57, x_{NTD}=7.74) and [tʌ] (x_{ASD}=5.05, x_{NTD}=6.31) were slower for children with ASD. Neither difference was statistically significant ($p<0.18$, $p<0.68$; $d>4.69$, 1.80, respectively). Conversely, syllable per second rates for [kʌ] (x_{ASD}=4.13, x_{NTD}=3.74) and [pʌtʌkʌ] (x_{ASD}=1.45, x_{NTD}=0.93) were faster for the ASD group. Neither difference was statistically significant ($p<0.34$, $p<0.33$; $d>0.47$, $d>1.45$ respectively).

Past research by these investigators has raised questions concerning the number of syllables produced by the different groups. Thus, further analyses into the number of syllables and the length of productions were calculated.

The ASD group consistently produced nearly half the number of syllables than their NTD peers. These differences were statistically significant for [pʌ] ($p<0.02$; $d>0.95$), [tʌ] ($p<0.01$; $d>1.50$) and [kʌ] ($p<0.02$; $d>1.22$), although not for [pʌtʌkʌ] ($p<0.07$, $d>0.92$) (Table 10).

Analyses into the length of time required to produce the syllables, as seen in Table 11, revealed a similar trend. As expected when producing fewer numbers of syllables, the length of production was also reduced for the ASD group. Hence, when calculating a syllable per second rate, fewer syllables in a shorter time frame resulted in similar rates to those of the NTD group. Thus, this further investigation revealed that a difference characterized by fewer syllable repetitions is present for the ASD group.

3.1.4. Formants

Formant values provide the listener with important information regarding the vowel heard. Achieving accurate and consistent formant values is key to speech intelligibility.

3.1.4.1. [a]

Formant data for the vowel [a] revealed that the ASD group produced lower formant values as compared to the NTD group. On an individual level, children with ASD were more variable for F1 and F3. With regard to group variability, the ASD group was more variable for F2 only.

Differences between groups on the first two formants were not significant ($p<0.58$, $p<0.17$; $d>0.03$, $d>0.70$, respectively), although they were for the third formant ($p<0.04$, $d>0.89$). Please see Table 12 for these comparisons.

3.1.4.2. [i]

Consistent with this study’s findings regarding lower formants for the vowel [a], children with ASD demonstrated lower formant values for all three formant frequencies of the vowel [i]. These non-statistically significant differences ($p_{F1}<0.43$, $d>0.55$; $p_{F2}<0.15$, $d>0.47$; $p_{F3}<0.10$, $d>0.61$) can be viewed in Table 13. The ASD group was more consistent, both individually and as a group, for F1 and F3. Individual variability was higher for F2, while group variability was lower.

3.1.4.3. “pea tea key”

Formants were obtained for each of the [i] vowels within the words “pea,” “tea” and “key.” Table 14 illustrates the values obtained for each of the groups’ F1, F2 and F3 formant values across the three [i] vowels.

While producing “pea” and “tea,” the ASD group demonstrated higher formant values for F1 (x_{peaF1}=577.05 Hz, x_{teaF1}=524.98 Hz) than their NTD peers (x_{peaF1}=368.88, x_{teaF1}=398.47). This was in contrast to the lower observed values for F2 within the ASD group (x_{peaF2}=2790.97, x_{teaF2}=2773.69) as compared to the NTD group (x_{peaF2}=2990.24, x_{teaF2}=2998.21). The differences between the second formants were statistically significant for both “pea” ($p<0.05$, $d>0.71$) and “tea” ($p<0.01$, $d>0.96$). The third formants for both “pea” and “tea” were lower within the ASD group, and maintained a statistically significant difference.

As noted earlier, the durations of [i] within “key” resulted in a statistically significant difference. However, the formant values did not reveal similar differences. Indeed, the pattern of formant value differences was unique to this word. As opposed to higher formants for F1 with lower F2 and F3 values as were found for the words “pea” and “tea,” “key” revealed higher F1 and F2 values, with lower F3 values.

3.1.5. Pitch

As stated previously, a male child between the ages of five and eight years old is expected to have a fundamental frequency of 250-265 Hertz (Hz), whereas a female child of the same age is expected to have a fundamental frequency between approximately 255-265 Hz (Baken & Orlikoff, 2000; Roth & Worthington, 2005).

3.1.5.1. [a]

A nearly equal pitch value was observed for the vowel [a] within the ASD group as within the NTD group. The average pitch for the ASD group was measured at 203.41 Hz, and at 204.28 Hz for the NTD group. With a significance level of $p<0.94$ ($d>0.03$), this suggests that the pitch levels between the two groups were nearly equal. Table 15 is available for reference purposes. Individually, participants with ASD were more variable, although as a group they were more consistent. This suggests that pitch may vary across different speech tokens for each child.

3.1.5.2. [i]

Also detailed within Table 15 are the results of fundamental frequency calculations for the vowel [i], as produced in isolation. Consistent with findings for lower formant values, the ASD group presented with lower pitch values (x_{ASD}=188.68 Hz, x_{NTD}=203.33 Hz), which was a statistically significant difference ($p<0.04$; $d>0.74$). Similar to the [a] pitch results, the ASD group was more variable on an individual level but more consistent as a group.

3.1.5.3. “pea tea key”

Pitch results of the short phrase “pea tea key” suggest that children with ASD alter their pitch within the phrase. Lower pitch values were observed for the first two vowel tokens, while higher pitch values were found for the third vowel token for both individual participants and group averages. Pitch values for each vowel are displayed within Table 16.

3.1.6. Voice Measurements

Measurements discussed within this section were obtained from the Multi-Dimensional Voice Profile (MDVP) program from Kay Pentax. Analyses were performed upon the vowels [a] and [i], the elicited speech tasks counting 1-10 and singing Happy Birthday, as well as the spontaneous speech tasks Story 1, Story 2, and Topic of Interest. Group data for the vowels are discussed in terms of averages across the three tokens, while the elicited and spontaneous speech tasks were obtained once each.

3.1.6.1. Fundamental Frequency Measurements

Fundamental frequency measurements are associated with measurements of pitch. Unlike the measurements of the same utterances obtained from the Multi-Speech program, these results, found in Tables 17-19, indicated that the ASD group presented with higher average pitch across all speech tasks. There were statistically significant differences for Happy Birthday ($p<0.03$, $d>1.32$), Story 1 ($p<0.02$, $d>1.40$), and the Topic of Interest ($p<0.01$, $d>1.39$).

The observed trend of higher pitch values continued across the highest and lowest observed fundamental frequencies. The Highest Fundamental Frequency was observed to be higher for the ASD group across all tasks. Statistically significant differences were observed for Happy Birthday ($p<0.02$, $d>1.49$), Story 1 ($p<0.04$, $d>1.07$), Story 2 ($p<0.04$, $d>1.00$), and Topic of Interest ($p<0.05$, $d>1.22$). With the exception of Story 2, the Lowest Fundamental Frequency was also higher for the ASD group. None of these differences were found to be statistically significant.

In regard to the Standard Deviation of Pitch, a measure of the variability of pitch, this was also found to be higher for the ASD group and for some individuals with ASD. Greater variability of pitch was found to be in accordance with the data obtained from the Multi-Speech. All spontaneous speech tasks revealed statistically significant differences ($p<0.02$, 0.03, 0.01; $d>0.92$, $d>1.05$, $d>1.43$ respectively).

The measurement Phonatory f0 Range in Semitones expresses the range between the highest and lowest fundamental frequencies, as measured in semi-tones (Kay Pentax, 1993). A greater number of semi-tones, representing a larger range between highest and lowest fundamental frequencies, was found across all tasks for the ASD group. No differences were statistically significant. A greater number of Semitones can be attributed to an increase in variability, not necessarily the presence of more prosody.

3.1.6.2. Short- and Long-Term Frequency Perturbation Measurements

Short- and long term-frequency perturbation measurements are concerned with the variability of pitch. The most widely studied of these measures is jitter, a measure of short-term variability (Kay Pentax, 1993), which has been found to be higher in pathological voices. Jitter is measured through two different calculations in MDVP. Both of these (Jitter Percent and Absolute Jitter) revealed values that were lower for the ASD group for the vowels along with the elicited and spontaneous speech tasks. Results may be viewed in Tables 20-22. Mean Absolute Jitter differences were statistically significant for Counting, Happy Birthday and for the Topic of Interest ($p<0.01$ for all; $d>1.23$, $d>1.68$, $d>1.46$, respectively).

Additional measures of pitch variability, Relative Average Perturbation Quotient and Pitch Perturbation Quotient, are both calculated with smoothing factors applied to the analysis. Smoothing factors have been shown to affect the length of the variability period to which the measure is most sensitive. They are calculated by "subtracting the average of a group of successive periods from the middle period; the period number that is averaged is called the smoothing factor" (Kahraman & Yildirim, 2011). Thus, lower smoothing periods are sensitive to short-term variability, while higher smoothing periods are sensitive to long-term variability (Kahraman, Kilic & Yildirim 2001). Smoothing factors are automatically set at 3 and 55 periods for Relative Average Perturbation and Pitch Perturbation Quotient, respectively. As with other variables of this type, values were lower for the ASD group on all tasks except [i]. The only statistically significant difference was found for Relative Average Perturbation

Quotient for Counting ($p<0.05$, $d>1.05$), suggesting that a notably higher pitch variability was seen in the ASD group.

Two measures of long-term pitch variability are the Smoothed Pitch Perturbation Quotient and the Fundamental Frequency Variation. Both sets of values were noted to be higher within the ASD group for all tasks except Happy Birthday. This task did not follow these trends, instead revealing a lower value for the Smoothed Pitch Perturbation Quotient, and a nearly equal value for the Fundamental Frequency Variation.

3.1.6.3. Short- and Long-Term Amplitude Perturbation Measurements

In opposition to the previously described measures lie the measurements of short- and long-term amplitude perturbation, which look at the variability of the amplitude. Amplitude perturbation, or shimmer, is the most widely studied of these variables. As with jitter, increased measures of shimmer are associated with voices comprised of aperiodic acoustic waves, such as pathological voices, with greater frequency perturbation. Furthermore, it has been suggested that jitter and shimmer may covary (Heilberger & Horii, 1982, as cited by Baken & Orlikoff, 2000, p. 131).

Shimmer values varied in their presentation across tasks. While the values were higher for [i] and Story 2, they were lower for Counting, Happy Birthday, and Story 1, while remaining similar across groups for [a] and Topic of Interest. No tasks revealed statistically significant differences. Please consult Tables 23-25 for all results.

Both the Amplitude Perturbation Quotient and the Smoothed Amplitude Perturbation Quotient are calculated with smoothing factors, the latter with higher factors than the former. The shorter-term variability calculated within the Amplitude Perturbation Quotient revealed higher ASD group variability for the vowels, Story 2, and the Topic of Interest, with lower variability for Counting, Happy Birthday and Story 1. Alongside this was increased ASD long-term variability, as calculated by the Smoothed Amplitude Perturbation Quotient, for the vowels and spontaneous speech tasks, with decreased long-term variability for the elicited speech tasks. The sole statistically significant difference existed for the Smoothed Amplitude Perturbation Quotient of Story 2 ($p<0.05$, $d>1.08$), on which the ASD participants were more variable.

The last measure within this set, Peak-to-Peak Amplitude Perturbation, investigates the standard deviation of amplitude, the longest-term measure of variability. This was found to be higher for all tasks except Happy Birthday. The second story revealed a statistically significant difference ($p<0.00$, $d>1.78$).

3.1.6.4. Noise-Related Measurements

The various noise-related measurements calculate the inharmonic components of voice in relation to the harmonic components.

The Noise-to-Harmonics Ratio (NHR) evaluates the general presence of noise within the voice sample. Across all samples, this value, as seen in Tables 26-28, was observed to be the same, or nearly the same, for the ASD group as for the NTD group.

The Voice Turbulence Index (VTI) measures high frequency noise, and is associated with incomplete or loose adduction of the vocal folds (Kay Pentax, 1993). No statistically significant results were discovered, nor did a distinct pattern emerge. ASD values were higher for the vowel [i] and the first story, while they were lower for all remaining tasks.

The third measurement, the Soft Phonation Index (SPI), is an average of the low frequency harmonics to the high frequency harmonics, and is also associated with incomplete or loosely adducted vocal folds. It has been suggested that the measure is sensitive to vowel formants; it is recommended for [a] only. With respect to the vowel [a] measured in this study, the SPI of children with ASD was lower.

3.1.6.5. Tremor-Related Measurements

This group of measurements probes the relationships between two modulating components to the total measure.

Specifically, the f0 Tremor Intensity Index calculates the ratio of the lowest frequency-modulating component to the total frequency magnitude. A high value on this measure would indicate higher levels of tremor. Amongst the participants with ASD, values for this measure were lower for elicited speech tasks, but higher for spontaneous speech tasks. This was significant for Story 2, ($p<0.01$; Tables 29-31). On the other hand, the Amplitude Tremor Intensity Index calculates the ratio of the lowest frequency amplitude-modulating component to the total amplitude magnitude. A high value on this measure would indicate higher levels of tremor. These values followed the same pattern as those for the f0 Tremor Intensity Index.

Two additional measures, the f0 Tremor Frequency and the Amplitude Tremor Frequency (ATF), can only be calculated if the corresponding tremor intensity index was also calculated. These values were not calculated for [a] and were inconsistently calculated for [i], possibly due to the absence of tremor in the sustained vowels; thus, they will not be addressed for the vowels. For the elicited speech tasks, the values were lower while for the spontaneous speech tasks they were higher. No differences were statistically significant.

3.1.6.6. Voice Break-Related Measurements

Two measures, Degree of Voice Breaks (DVB) and Number of Voice Breaks (NVB), fall within this category. They are most salient for sustained phonation tasks, i.e., vowels, where voice breaks are atypical. Results are detailed in Tables 32-34. Although the results were non-significant, it is important to note that both measures were higher for the ASD [a] productions. However, for the production of [i], these values were approximately the same amongst participants with ASD as for NTD participants. It is plausible that the vowel [i] is a more stable vowel, resulting in fewer occurrences of voice breaks. Research supports this theory, with [i] being a more stable vowel when produced at medium to low intensities, and [a] being more stable at high intensities (Gelfer, 1995).

3.1.6.7. Voice Irregularity-Related Measurements

The penultimate group of measurements estimates non-harmonic segments within a voice sample. As with previous measures, it is assumed that any presence of voice irregularities on sustained phonation tasks is atypical. These values were higher for the ASD group, without the group differences being statistically significant. Please consult Tables 35-37 for full details.

3.1.6.8. Sub-Harmonic Related Measurements

Within the final grouping of variables can be found measurements pertaining to the presence of sub-harmonics. Sub-harmonics are those frequencies that are a fraction, i.e., ½ or ¼, of the fundamental frequency. Degree of Sub-Harmonics evaluates the frequencies of the sub-harmonics relative to the fundamental frequency, while the Number of Sub-Harmonics counts how many sub-harmonics were found. These values were observed to be inconsistently present, and in some cases were higher for the ASD group, while in other cases they were lower for the ASD group. Elicited versus spontaneous speech did not appear to affect these patterns. Readers are encouraged to view Tables 38-40 for further details.

3.2. Perceptual Results

Perceptual results utilizing the CAPE-V were obtained from two groups of perceptual judges: the novice group, comprised of 12 Master’s degree students, along with the expert group which included four doctoral students, one university clinical supervisor, and an expert in voice. Ratings were obtained from the connected speech samples of counting 1-10, singing Happy Birthday, telling a story based on two wordless illustrated stories (Story 1 and Story 2), as well as discussing a topic of interest. Not all participants provided samples for these purposes, as detailed within the Methods- Tasks section.

3.2.1. Novice Group Perceptual Results

Cronbach’s alpha was calculated for each parameter of every task, e.g., for Overall Severity of Counting, Breathiness of Counting, etc. Alpha levels of .70 or greater are considered to be acceptable for statistical purposes. Mann-Whitney U data, comparing the perceptual ratings across participant groups (ASD versus NTD) are reported within tables for comparison purposes only.

Visual inspection of the data revealed a wide range of scores. Figure 2 details the results of the parameter

Overall Severity for the task Counting 1-10. Ratings for Judge 1 reflect the ratings of the most expert judge, who was included in the chart as a reference point. The corresponding results of the Cronbach's alpha, which ranged from 0.58 to 0.80, can be viewed in Table 38. Combined, this suggested that the ratings completed by the Novice Group varied considerably and were unlike those of the voice expert (Judge 1).

Similar inspection of the remaining data, the numerical results of which can be viewed in Tables 39-42, revealed comparable trends. These data were removed from further analyses due to its high levels of variability and inconsistency.

3.2.2. Expert Group Perceptual Results

As with the Novice group ratings, Cronbach's alpha was calculated for each parameter of every task, e.g., for Overall Severity of Counting, Breathiness of Counting, etc. Alpha levels of 0.70 or greater are considered to be acceptable for statistical purposes. To compare the perceptual ratings across participant groups (ASD versus NTD), a Mann-Whitney U was calculated.

Visual inspection of the data revealed a smaller range of scores as compared to those of the Novice Group. Figure

3 details the results of the parameter *Overall Severity* for the task Counting 1-10. Although there were clearly two points outlying (Judge 1, ASD4, and Judge 5, ASD15), the data appeared to be much more consistent amongst the judges. Additionally, the values from the various judges were similar to those from the voice expert, who was Judge 4 in this case. The corresponding results of the Cronbach's alpha, which ranged from 0.37 (Loudness) to 0.78 (Roughness), can be viewed in Table 46. Combined, this information suggests that the results from the Expert Group are reliable and valid for further analysis. These analyses are reported immediately below.

3.2.2.1. Counting

With regard to reliability for this task, the parameter of Loudness was the most difficult to measure ($\alpha=0.37$), with the remaining parameters ranging from a moderate reliability to a strong reliability for Roughness ($\alpha=0.78$).

The Overall Severity parameter revealed similar levels of judged vocal severity for the ASD versus NTD group ($x_{ASD}=12.15$ and $x_{NTD}=12.73$; the differences were not statistically significant ($p<0.77$, $d>0.09$), as can be seen in Table 46. The results for Strain were also similar between the two groups.

The ASD group was perceived as having a pitch difference from typical values (x_{ASD}=8.88 and x_{NTD}=4.97, $p<0.06$, $d>0.65$). This difference varied, as some judges reported it as low pitch, while one other judged it as monopitch. Although not included on the CAPE-V scale, several judges described an additional parameter of pitch instability. An increased level of Loudness was also reported for the ASD group (x_{ASD}=8.47 and x_{NTD}=5.10, $p<0.73$, $d>0.57$).

Perceptions of Roughness and Breathiness revealed that the participants with ASD presented with lower levels of these characteristics. Indeed, the values for Roughness were nearly half for the ASD group (x_{ASD}=4.74 versus x_{NTD}=9.82, $p<0.16$, $d>0.76$), while for Breathiness values were a third of those for the NTD group (x_{ASD}=2.66, x_{NTD}=7.88, $p<0.11$, $d>1.03$).

In addition to the numerical data obtained from the CAPE-V, several of the judges provided qualitative comments regarding the nature of the recordings. Appendix C contains these comments. ASD1 was noted to present with “choppy, awkward phrasing, vocal quality appears normal except for breathiness and slight roughness” (Judge 1), as well as omission of final consonants (Judge 6). Choppy phrasing was noted for ASD4 by both Judge 1 and 6, along with an increased rate and decreased duration and a staccato/robotic affect (Judge 2). Judge 2 questioned whether or not ASD10 was ataxic or apraxic, due to the child's decreased coordination of respiration. Minor misarticulations, including the presence of a lateral lisp and difficulties with /r/ blends, were noted for some NTD participants.

Judges also commented on perceived nasality, i.e., whether a sample was hyponasal or hypernasal. Two subjects from the ASD group were noted to have atypical nasality by more than one judge. ASD11 was described as being hypernasal by one judge, and hyponasal by two other judges. Similarly, ASD12 was perceived as being both hypernasal and hyponasal. The second judge described ASD5 as follows, "I can't put my finger on it; the child sounds hypo until 'nine,' then sounds hypernasal."

3.2.2.2. Happy Birthday

Both the Roughness and the Breathiness parameters produced reliable results for this task with Cronbach's alpha values greater than 0.70, at 0.78 and 0.74 each. Pitch produced a questionable reliability at 0.67, while the remaining parameters indicated unacceptable to poor reliability with Cronbach's alphas ranging from 0.25 to 0.46. Results may be viewed in Table 47.

Overall Severity was judged by the expert group to be slightly higher for the ASD group ($x_{ASD}=12.67$) as opposed to the NTD group ($x_{NTD}=11.86$), although this difference was not statistically significant ($p<0.301$). The ASD group also presented with higher ratings for Strain ($x_{ASD}=3.58$, $x_{NTD}=2.40$, $p<0.24$, $d>0.46$), Pitch ($x_{ASD}=10.09$, $x_{NTD}=5.21$, $p<0.16$, $d>0.57$) and Loudness ($x_{ASD}=5.42$, $x_{NTD}=54.96$, $p<0.27$, $d>0.08$).

Conversely, for both Roughness and Breathiness, the values present for the ASD group were approximately half of those for the NTD group ($x_{ASD}=4.97$, $x_{NTD}=8.23$, $p<0.86$, $d>0.57$; $x_{ASD}=4.55$, $x_{NTD}=9.92$, $p<0.46$, $d>0.77$, respectively).

Qualitatively, ASD4 was noted again to present with decreased coordination among his articulatory, phonatory and respiratory systems, causing the second judge to question if he was apraxic or ataxic. Judges 2 and 6 also noted a difference in prosody. A similar difficulty in coordination, phonation, and respiration was observed for ASD4 by Judge 6, which resulted in even stress on words. Even stress on words was also noted for ASD9 by this judge, who further qualified that the subject had a low pitch and sounded as if he was singing at the end of his pitch range. Difficulties with producing a wide pitch range were present for two NTD participants, along with several articulatory errors for five of these participants.

Differences in nasality for ASD1 and ASD3 were noted by more than one judge, although there was inconsistency regarding in what way the nasality sounded different. ASD1 was judged as having both a hyper- and a hypo-nasal quality, while ASD3 was rated once as presenting with a hyper- and twice as presenting with a hypo-nasal quality.

3.2.2.3. Story 1

Three parameters produced reliable and consistent results amongst the Expert Judges for this task. These were Overall Severity ($\alpha=0.77$), Roughness ($\alpha=0.83$), and Strain ($\alpha=0.73$). The remaining three parameters obtained questionable reliability at $\alpha=.68$ (Breathiness), and poor reliability at 0.52 (Loudness) and 0.58 (Pitch).

Larger differences in vocal quality were observed for this task, as indicated by increased Overall Severity values for both groups. This increase occurred in an overall fashion, and did not create differences between the two groups, ($x_{ASD}=18.17$, $x_{NTD}=17.93$, $p<0.92$, $d>0.02$).

Although the differences were not statistically significant, the ASD group was judged to have increased Pitch and Loudness values (x_{ASD}=8.45, x_{NTD}=5.69, $p<0.87$, $d>0.41$; x_{ASD}=10.62, x_{NTD}=8.75, $p<1.00$, $d>0.27$). Values for Strain, as displayed in Table 48, were similar between the two groups, with a slightly lower value for the ASD group (x_{ASD}=8.48, x_{NTD}=9.04, $p<0.71$, 0$d>0.06$).

A notable difference between groups for Roughness and Breathiness was observed. Roughness was judged to be nearly half for the ASD group (x_{ASD}=6.80, x_{NTD}=12.62, $p<0.82$, $d>0.59$). Breathiness was judged at 4.96 for the ASD group, and 7.51 for the NTD group, with $p<0.76$ ($d>0.36$).

The judges provided a plethora of qualitative comments regarding their perceptions of the story samples. Several clear patterns arose from their comments. Most commonly, prosodic speech qualities were atypical for ASD4, ASD9, ASD10 and ASD11. A “choppy” quality of speech was prevalent, appearing for ASD4, ASD8, and ASD11. Both ASD4 and ASD7 were noted to produce stress in an atypical fashion. Pitch differences were also noted for ASD4 and ASD10. Mild dysfluencies were also noted for ASD12 and ASD15. In addition to articulatory/phonological differences noted for several members of the NTD sample, both NTD2 and NTD15 were noted to produce “choppy” speech patterns.

On this task, differences in nasality were noted only for ASD12. All six judges reported such a difference, although there was discord in their reports. Four judges reported a perceived hypernasality, while two judges reported a perceived hyponasality.

3.2.2.4. Story 2

For this task, reliability calculations revealed that the Overall Severity and the Roughness parameters produced strong results at 0.75 and 0.87, respectively. Questionable reliability results were present for Breathiness (0.63) and Strain (0.63), with unacceptable reliability results for Pitch (0.42) and Loudness (0.36).

Reports of Overall Severity nearly reached a statistically significant difference ($p<0.05$, $d>0.28$) between the groups, with the ASD group rated worse ($x=17.08$) than the NTD group (14.62).

Perceptions of Strain, Pitch, and Loudness suggested a higher level of impairment for the ASD group, as can be seen in Table 49. None of these differences were statistically significant, however. With regard to Roughness and Breathiness, these were perceived as less impaired for the ASD group.

The judges noted a striking trend for pitch differences, often described as “pitch instability” for all ASD participants who completed this task. Similarly, differences in prosody were noted for seven of the 11 ASD participants included in the sample. Even stress on words was present for ASD3, ASD6, ASD12 and ASD15. Dysfluencies were heard for two ASD participants (7 and 11), as well as for NTD10. “Choppy” speech was noted for NTD2 only.

Trends in nasality were more consistent within this task. Of the three ASD participants who were perceived as having differences in nasality, two judges judged ASD6 as being hyponasal, three judges rated ASD11 as hyponasal, and five judges judged ASD12 as hyponasal with one judge rating ADS12 as hypernasal.

3.2.2.5. Topic of Interest

A single parameter reached a level of consistency to allow for further analysis, Strain, at $\alpha=0.77$. Two parameters, Roughness and Breathiness obtained questionable levels of reliability. The Overall Severity reliability was poor, and reliability for Pitch and Loudness was unacceptable.

Mildly impaired vocal qualities were noted for the ASD group as shown through the Overall Severity rating (x=15.54), as well as for the NTD group (13.95), with a non-statistically significant difference (p<0.49, d>0.20).

Table 50 displays a continuing trend for higher values for Strain, Pitch, and Loudness for the ASD group (x=8.58, 7.13, 7.41, respectively) in comparison to the NTD group (x=5.43, 4.33, 4.70, respectively). No differences reached a level of statistical significance (p<0.36, 0.36, 0.287; d>0.47, d>0.50, d>0.47 respectively). Additionally, Roughness and Breathiness were rated once again as more mildly impaired for the ASD group (x=3.82 and 2.15) than the NTD group (x=9.36, 7.13).

Differences in pitch and prosody were again apparent for many participants with ASD. ASD participants 3, 4, 5, 6 and 9 were perceived as having pitch instabilities along with prosodic differences for ASD 7, 8, 9, 10 and 11. Judge 1 describes the pitch of ASD4 as "poor pitch control & monopitch, seems odd to write both, but you could tell he's more monopitch most of the time but is trying to produce a question- and this is not well controlled when he attempts it." Dysfluencies were observed for ASD 6, ASD10 and ASD15, as well as NTD4 and NTD15. Stress was off for NTD8 only.

ASD participants were most frequently reported to exhibit a hyponasal feature, as reported by two judges for

ASD3, by two judges for ASD11, and by three judges for ASD12 with one conflicting report of hypernasality.

3.3. Correlational Results

Each parameter from the Expert Group ratings that reached an acceptable level of reliability, i.e, a Cronbach's alpha of 0.700 or greater, was then subjected to a bivariate correlation to investigate the acoustic voice parameters obtained by the MDVP program that may contribute to a listener's perception of each parameter. Thus, the following parameters were analyzed further: Roughness (Counting, Happy Birthday, Story 1, Story 2), Overall Severity (Story 1, Story 2), Strain (Story 1, Topic of Interest), and Breathiness (Happy Birthday).

3.3.1. Counting - Roughness

Of the 22 voice parameters analyzed by the MDVP program, eight of these produced a strong, statistically significant, correlation with the perceptual parameter Roughness on the Counting task. These included the long-term frequency perturbation measure Smoothed Pitch Perturbation ($p<0.03$); the short- and long-term amplitude perturbation measures Shimmer in dB ($p<0.03$), Shimmer in Percent ($p<0.01$), Amplitude Perturbation Quotient ($p<0.00$);

the tremor-related measurements f0 Tremor Intensity Index ($p<0.00$) and Amplitude Tremor Intensity Index ($p<0.04$); and the sub-harmonic measurements Degree of Sub-Harmonics ($p<0.00$) and Number of Sub-Harmonics ($p<0.00$).

An additional five parameters were moderately correlated with Roughness, including Absolute Jitter ($p<0.52$), Jitter Percent ($p<0.71$), Relative Average Perturbation ($p<0.147$), Fundamental Frequency Variation ($p<0.115$), and Amplitude Perturbation Quotient ($p<0.084$). These five parameters reflect short- and long-term frequency perturbation, as well as long-term amplitude perturbation.

Most measures of fundamental frequency revealed small correlations with Roughness, with the exception of Highest Fundamental Frequency, which had a weak correlation (Table 51).

As stated previously, short- and long-term frequency perturbation measurements produced strong to moderate sized correlations, with the exception of a small correlation found for Relative Average Perturbation. Similarly, all short- and long-term amplitude perturbation measurements displayed strong to moderate correlations, excepting a weak correlation with Peak-to-Peak Amplitude Variation.

Noise-related measurements produced only small correlations with Expert Judges' ratings of Roughness on the Counting task. While two parameters were statistically significant within tremor-related measurements, the Amplitude Frequency measure had a weak correlation. Voice-break related measurements revealed small correlations, along with voice irregularity measurements. All measures for sub-harmonics suggested strong correlations.

3.3.2. Happy Birthday - Roughness

Analysis of the correlations between Judges' perceived Roughness from the Happy Birthday task and the 22 voice variables calculated by MDVP indicated that no MDVP voice variables were strongly correlated with the Roughness percept.

Moderate correlations with Roughness were present for the fundamental frequency measures Standard Deviation of f0 ($p<0.20$) and Phonatory f0 range in Semi-Tones ($p<0.15$) as well as for the short-term frequency perturbation measures Jitter Percent ($p<0.11$), Relative Average Perturbation ($p<0.13$), and Pitch Perturbation Quotient ($p<0.10$). The remaining measures within both of these groups had small correlations with Roughness.

Small to weak correlations with Roughness were discovered for all remaining voice variables. Please consult Table 53 for further information.

3.3.3. Story 1 - Roughness

A variety of strongly- to moderately-correlated items resulted in statistically significant correlations with the parameter Roughness, as perceived by the Expert Judges' during the Story 1 task. These ten variables included the fundamental frequency variable Average Pitch Period ($p<0.04$); short- and long-term frequency perturbation measures Absolute Jitter ($p<0.00$), Jitter Percent ($p<0.02$), Relative Average Perturbation ($p<0.00$), Smoothed Pitch Perturbation Quotient ($p<0.00$), and Fundamental Frequency Variation ($p<0.00$); short-term amplitude perturbation measure Shimmer in Percent ($p<0.02$); both sub-harmonic measures Degree of Sub-harmonics ($p<0.01$) and Number of Sub-Harmonics ($p<0.04$); and the voice irregularity measure Total Number Detected Pitch Periods ($p<0.03$).

Beyond these measures, an additional seven measures revealed a moderate correlation with the percept of Roughness on Story 1. The fundamental frequency measures Average Fundamental Frequency ($p<0.11$), Mean Fundamental Frequency ($p<0.06$), Lowest Fundamental Frequency ($p<0.12$), and Standard Deviation of f0 ($p<0.09$); short- and long-term amplitude perturbation measures Shimmer in dB ($p<0.17$) and Amplitude Perturbation Quotient ($p<0.19$); along with the voice break measure Degree of Voice Breaks ($p<0.09$) comprised this group.

Highest Fundamental Frequency and Phonatory f0 range in Semi-Tones, detailed in Table 55, did not meet the same moderate to strong correlations with Roughness on Story 1 that the majority of the fundamental frequency measures met, nor did the Pitch Perturbation Quotient or Peak-to-Peak Amplitude Perturbation Quotient from the short-term frequency and amplitude perturbation measures. Noise- and tremor-related measures produced weak to small correlations with perceived Roughness, as did the voice irregularity measurements except for Total Number Detected Pitch Periods.

3.3.4. Story 2 - Roughness

When judging Roughness for the spontaneous speech task Story 2, judges were most affected by atypicalities in short- and long-term frequency perturbation measures. Indeed, all of these measures returned strong to moderate, statistically significant, correlations. These values can be viewed in Table 58. An additional statistically significant correlation with Story 2 Roughness was present for Standard Deviation of f0 ($p<0.02$).

Three moderate correlations were found for Lowest Fundamental Frequency ($p<0.17$), Shimmer in Percent ($p<0.08$) and Noise to Harmonics Ratio ($p<0.13$).

Nearly all of the remaining variables revealed small correlations with Story 2 Roughness, except for weak correlations found within the short- and long-term amplitude perturbation measurements, noise related measures and voice irregularity measures.

3.3.5. Story 1 - Overall Severity

The Expert Judges' perceptions of the Overall Severity of the spontaneous speech task Story 1 were found to be strongly correlated to Absolute Jitter ($p<0.01$), Relative Average Perturbation ($p<0.01$), Smoothed Pitch Perturbation Quotient ($p<0.00$), Fundamental Frequency Variation ($p<0.04$), Shimmer in Percent ($p<0.03$), Degree of Voiceless ($p<0.01$), and Number of Unvoiced Segments ($p<0.01$). These measures reflect short- and long-term amplitude and frequency perturbation, and voice irregularity measurements.

Moderate correlations with Overall Severity also were found for additional variables within those groups, including Jitter Percent ($p<0.08$), Shimmer in dB ($p<0.11$), Amplitude Perturbation Quotient ($p<0.08$), and Total Number Detected Pitch Periods ($p<0.10$). Additionally, Standard Deviation of f0 ($p<0.13$), Soft Phonation Index ($p<0.19$) and Degree of Voice Breaks ($p<0.123$) were moderately correlated with Overall Severity on this task.

Overall, fundamental frequency measures produced weak to small correlations with Overall Severity, excepting the one variable discussed previously. On the other hand, most variables for short- and long-term frequency and amplitude perturbation measures were moderately to strongly correlated with this judgment. Noise-, voice break-, and sub-harmonic-related measurements were mostly small correlations. Full details can be found within Table 54. All tremor-related measures produced weak correlations with Overall Severity. Voice irregularity measurements exhibited a combination of strong and moderate correlations.

3.3.6. Story 2 - Overall Severity

The most significant correlations to Expert Judges' perceived Overall Severity on the Story 2 task arose from short- and long-term frequency perturbation measurements, including Absolute Jitter ($p<0.05$), Jitter Percent

($p<0.01$), Pitch Perturbation Quotient ($p<0.03$), and Fundamental Frequency Variation ($p<0.05$). One additional parameter, Standard Deviation of f0, also had a strong correlation ($p<0.05$) with Overall Severity on this task.

The contribution of short- and long-term frequency perturbation measurements was further strengthened by moderate correlations from Relative Average Perturbation ($p<0.07$) and Smoothed Pitch Perturbation Quotient ($p<0.07$). Two additional measures, Noise to Harmonics Ratio ($p<0.09$) and Degree of Sub-Harmonics ($p<0.23$) also exhibited a moderate correlation with perceived Overall Severity.

Excepting the strong correlation found for Standard Deviation of f0, the variables of fundamental frequency displayed weak to small correlations with the Overall Severity percept. Short- and long-term amplitude perturbation measures, along with noise, tremor, voice break, and voice irregularity measures displayed the same pattern. Further information may be gleaned from Table 57.

3.3.7. Story 1 - Strain

Both short- and long-term frequency and amplitude perturbation measures were present in the group of variables strongly correlated to Expert Judges’ perceived Strain during the task Story 1, as seen in Table 56. These highly-related measures were Smoothed Pitch Perturbation Quotient ($p<0.00$), Fundamental Frequency Variation ($p<0.04$), Shimmer in Percent ($p<0.03$), and Amplitude Perturbation Quotient ($p<0.02$).

Eight variables representing five voice components exhibited a moderate correlation with the percept Strain. Of these eight variables, three were from the voice irregularity group including Degree of Voicelessness ($p<0.09$), Number of Unvoiced Segments ($p<0.09$), and Total Number Detected Pitch Periods ($p<0.06$). Standard Deviation of f0 ($p<0.15$) from the fundamental frequency measures; Shimmer in dB ($p<0.12$) and Smoothed Amplitude Perturbation Quotient ($p<0.08$) from the short- and long-term amplitude perturbation measures; the tremor measure Amplitude Frequency ($p<0.13$); and the voice break measure Degree of Voice Breaks ($p<0.18$) further contributed to the group of moderate correlations with perceived Strain on Story 1.

Most fundamental frequency measures produced small correlations with the Strain percept. Short- and long-term frequency perturbation measures, however, exhibited a variety of weak, small and strong correlations. Correlations with Strain from short- and long-term amplitude perturbation measures were mostly moderate to strong. Measures from noise, tremor, voice breaks and sub-harmonics were mostly small correlations, with the few exceptions noted above. Voice irregularity measures suggested moderate correlations with perceived Strain.

3.3.8. Topic of Interest - Strain

A total of seven MDVP variables were strongly correlated to the perceptual parameter Strain as judged for the task Topic of Interest. Fundamental frequency variables were most strongly associated with Strain, as Average Fundamental Frequency ($p<0.00$), Mean Fundamental Frequency ($p<0.006$), Average Pitch Period ($p<0.05$), Highest Fundamental Frequency ($p<0.03$), and Standard Deviation of f0 ($p<0.00$) were included in this group. The remaining two variables were Fundamental Frequency Variation ($p<0.01$), a measure of long-term frequency perturbation, and Noise to Harmonics Ratio ($p<0.01$), a measure of noise.

The contributions of fundamental frequency and noise measures were further strengthened by moderate correlations with Strain during the Topic of Interest task found for Phonatory f0 range in Semi-Tones ($p<0.18$), Voice Turbulence Index ($p<0.18$) and Soft Phonation Index ($p<0.21$). Smoothed Pitch Perturbation from the long-term frequency perturbation measures was also moderately correlated with perceived Strain, as can be seen in Table 59.

Most of the fundamental frequency measurements were moderately to strongly correlated, as were the long-term frequency perturbation measures, although the short-term frequency perturbation measures indicated small correlations. Short- and long-term amplitude perturbation measures were similar. Measurements pertaining to tremor, voice breaks, sub-harmonics and voice irregularity produced small to weak correlations with Strain on this task.

3.3.9. Happy Birthday - Breathiness

A total of four MDVP variables were strongly correlated to the Expert Judges' perceptual parameter Breathiness found on the Happy Birthday task. Results can be seen within Table 52. Two breathiness-correlated variables pertained to fundamental frequency: Average Pitch Period ($p<0.03$) and Lowest Fundamental Frequency ($p<0.04$), while two variables were related to long-term frequency perturbation: Smoothed Pitch Perturbation Quotient ($p<0.04$) and Fundamental Frequency Variation ($p<0.03$).

Beyond this, nine MDVP parameters produced a moderate correlation with the percept of Breathiness. Variables associated with fundamental frequency (Average Fundamental Frequency, $p<0.14$; Mean Fundamental Frequency, $p<0.19$; and Highest Fundamental Frequency, $p<0.05$) were most commonly associated with this perception, along with short-term amplitude perturbation measurements (Shimmer in dB, $p<0.06$; Shimmer in Percent, $p<0.07$; Amplitude Perturbation Quotient, $p<0.16$). A single measure of short-term frequency perturbation, Absolute Jitter ($p<0.06$), as well as Degree of Voiceless ($p<0.43$) and Number of Segments Computer ($p<0.17$), both from the grouping “voice irregularity measurements” were also moderately correlated with the judges’ percept of Breathiness.

Although the measures of Standard Deviation of f0, and Phonatory f0 range in Semi-Tones, both of which measure changes in fundamental frequency, revealed small correlations, the remaining parameters produced moderate to strong correlations with Breathiness. Similarly, most measures of short- and long-term amplitude and frequency perturbation were also strongly to moderately correlated with this perception. Noise-related, tremor-related, and voice break-related measurements produced small correlations. On the other hand, sub-harmonic related measures were weakly correlated with Breathiness. Two voice irregularity measurements produced medium correlations, as previously stated, along with small correlations for Number of Unvoiced Segments and Total Number Detected Pitch Periods.

3.4. Research Questions

1. Are there specific motor speech features that support probable underlying motor speech impairments, such as apraxia of speech and dysarthria that can differentiate children with ASD from children who are NTD?
    - Null hypothesis: There are no specific motor speech features that support probable underlying motor speech impairments, such as apraxia of speech or dysarthria, that can differentiate children with ASD from children who are NTD.
    - Alternate hypothesis: There are specific motor speech features that support probable underlying motor speech impairments, such as apraxia of speech or dysarthria, that can differentiate children with ASD from children who are NTD.

This research supports the rejection of the null hypothesis that there are no specific motor speech features that support probably underlying motor speech impairments, such as apraxia of speech or dysarthria, that can differentiate children with ASD from children who are NTD. In support of the alternate hypothesis, several characteristics have been identified, including decreased Maximum Phonation Times, lower formant values, lower pitch values, and smaller number of syllable repetitions during AMR and SMR tasks.

2. Are there specific perceptual features of speech that judges can reliably and consistently perceive, in order to differentiate the speech of children with ASD from that of children who are NTD?
    - Null hypothesis: There are no specific perceptual features of speech that judges can reliably and consistently perceive, in order to differentiate the speech of children with ASD from that of children who are NTD.
    - Alternate hypothesis: There are specific perceptual features of speech that judges can reliably and consistently perceive, in order to differentiate the speech of children with ASD from that of children who are NTD.

This research supports the rejection of the null hypothesis that there are no specific perceptual features of speech that judges can reliably and consistently perceive, in order to differentiate the speech of children with ASD from that of children who are NTD. In support of the alternate hypothesis exist several variables were identified, including reliability of Roughness, Overall Severity, and

Strain.

3. Are there specific acoustic variables that contribute to a listener’s perception of the parameters Overall Severity, Roughness, Breathiness, Strain, Pitch and Loudness?

- Null Hypothesis: There are no specific acoustic variables that contribute to a listener’s perception of the parameters Overall Severity, Roughness, Breathiness, Strain, Pitch and Loudness.
- Alternate Hypothesis: There are specific acoustic variables that contribute to a listener’s perception of the parameters Overall Severity, Roughness, Breathiness, Strain, Pitch and Loudness.

This research supports the rejection of the null hypothesis that there are no specific acoustic variables that contribute to a listener’s perception of the parameters Overall Severity, Roughness, Breathiness, Strain, Pitch and Loudness. In support of the alternate hypothesis are the clear and repetitive correlations of specific acoustic measures with Roughness, Strain, and Overall Severity.

Chapter 4

CONCLUSION

The results of this study have important ramifications for the understanding of speech differences within children with ASD. Previous hypotheses and research in the acoustic differences present for children with ASD were confirmed, alongside new contributions to the perceptual aspects of speech. Perhaps most importantly, the researchers sought to correlate perceptual aspects of speech to acoustic measures, revealing important correlations between the two. In the sections that follow, conclusions will be drawn and discussed in a larger framework based on the empirical findings detailed in this investigation.

4.1. Acoustic Findings

Acoustic analysis of speech provides a means to quantify the acoustic aspects of speech during an assessment. Providing that a certain set of controls are incorporated to reduce ambient noise levels and contaminating factors that may affect the quality of the acoustic signal, this methodology provides SLPs with a more objective means to measure voice and voice differences.

4.1.1. Maximum Phonation Time (MPT)

Participants within the ASD group presented with decreased MPT for both [a] (3 seconds, on average) and [i] (4.5 seconds, on average). Prolongations produced by this group were approximately two-thirds the length produced by their same-age peers. Normative data suggest that a neurotypical child between six and ten years of age should produce a MPT of nine seconds for the vowel [a] (Haynes & Pindzola, 2004; Kent, Kent & Rosenbek, 1987). In contrast, previous research by these authors had found children with ASD to produce MPTs of approximately 4 seconds (Boucher, Andrianopoulos and Velleman, 2007). The current data provide further evidence for the conclusion that children with ASD produce decreased MPTs as compared to children who are NTD.

Reduced MPT may be contributed to several factors, including reduced motor persistence, ideomotor deficits, or reduced motivation. Regardless of the cause, decreased Maximum Phonation Time remains a key characteristic of the motor speech and acoustic profile of children with ASD.

4.1.2. Duration

As a group, children with ASD produced longer utterance durations characterized by longer pause and vowel durations across tasks, including the phrase “pea tea key” and counting from 1-10. They were also more variable.

With regard to imitation of “pea tea key” increased vowel durations were found for all three vowels, although these differences reached statistical significance for the [i] of “key” only. In English, speakers signal the end of a phrase by increasing the duration and lowering the pitch, phenomena known as phrase-final lengthening and phrase-final declination, respectively. Data from the present study suggest that children with ASD are not using phrase-final lengthening and declination (see 4.1.5) in the expected manner. Children with ASD appear to display these acoustic changes to a lesser extent than NTD children. The length of the final vowel was not different from other vowels earlier in the phrase. That is, participants with ASD did not demonstrate phrase-final lengthening and phrase-final declination as compared to their NTD counterparts. Phrase-final lengthening and phrase-final declination were absent, i.e., all vowels were long and of approximately equal duration regardless of position. This fits within the general picture of children with ASD presenting with an overall slower rate of speaking than their NTD peers, as characterized by longer pause and vowel durations. Greater durational variability is also exhibited.

4.1.3. Alternate Motion Rates & Sequential Motor Rates

The ASD cohort produced an interesting pattern of AMR and SMR syllable-per-second rates. As a group, these children produced slower repetitions of [pʌ] and [tʌ], while their productions of [kʌ] and [pʌtʌkʌ] were faster. These differences were not statistically significant.

These investigators have hypothesized that the number of syllables produced by children with ASD is significantly less than the number of syllables produced by children who are NTD. These results were confirmed across all AMR and SMR tasks within this study. The ASD group consistently produced slightly less than half as many syllables as their NTD peers.

Indeed, the number of syllables produced resulted in a statistically significant difference between the groups for the AMR tasks. While results for [pʌtʌkʌ] were not significant, this may be due to reduced statistical power for this task. Of the twelve ASD participants whose data were analyzed, three (ASD2, ASD3, ASD4) participants were unable to produce any repetitions, and one participant (ASD14) was only able to produce one token. One participant who was NTD (NTD14) was unable to complete the task as well. Participants ASD14 and NTD14 were the youngest participants in the study at four and a half years of age, suggesting that they may not have yet developed sufficient motor control for the task. However, the three participants with ASD who were unable to produce any repetitions at all were far older (7;2 – 12;2). This suggests that achieving production of SMRs was difficult for a specific subset of children with ASD.

4.1.4. Formants

Lower formant values were found across tasks for participants with ASD. This was in contrast to data obtained previously (Boucher, Andrianopoulos & Velleman, 2007; Pecora, 2008) that suggested children with ASD presented with higher formant values. Additionally, the previous study suggested increased variability for the formant frequencies, while this study did not reveal consistent trends in that respect. Decreased group and individual variability was present for the vowel [i], suggesting that this vowel was more stable in its production.

Formants of the phrase “pea tea key” revealed interesting results, with increased F1 and decreased F2 values for the [i] of “pea” and “tea.” This suggests that the ASD group experienced a compression of formants between F1 and F2. A similar phenomenon was observed by Pecora (2008), although between formants F2 and F3. In her study, this pattern of compression was found to exist for the [i] of “key,” for which increased F2 with decreased F3 values were present.

4.1.5. Pitch

Pitch values for the vowel [a] were similar for both groups, while for [i], the ASD group produced lower pitch values. Lower pitch is in accordance with lower formant values. Individual variability was higher for all tasks.

Interestingly, for “pea tea key” the ASD group demonstrated lower pitch values for “pea” and “tea” with higher pitch values for “key.” Perceptually, this increase in pitch values at the end of the phrase may be perceived as a question instead of a statement. This suggests that children with ASD may have experienced difficulty interpreting and understanding the pitch of the investigators, who presented the task as a statement, and/or difficulty using their pitch in a similar manner, i.e., using phrase-final declination.

4.1.6. Voice Measurements

Analysis of connected speech tasks revealed that the ASD group produced higher pitch values for all connected speech tasks. This was in opposition to the lower observed pitch for vowels. Pecora (2008) discovered a similar phenomenon of participants with ASD demonstrating lower pitch during vowel production and higher pitch during connected speech.

Furthermore, results suggested that short-term pitch variability for children with ASD was decreased while long-term variability was greater. However, this was not true for the Happy Birthday task, although the lack of differences was perhaps due to the nature of task, which naturally included variability while singing.

Noise-related measures did not produce differences between the two groups. Tremor appeared to be decreased during elicited speech tasks and increased during spontaneous speech tasks for all participants.

Voice measurements for Story 2, in particular, revealed a wider pitch range and increased tremor. Given that this story contained an element of perspective taking, it is possible that the participants were picking up on this component, although they did not express it verbally.

4.2. Perceptual Results

Subjective measures of voice, such as the Consensus Auditory Perceptual Evaluation of Voice (CAPE-V; (CAPE-V; American Speech Language Hearing Association Special Interest Division 3 Voice and Voice Disorders, 2006) are an essential component of understanding voice characteristics. Perceptual ratings such as these help to complement and standardize the acoustic measurement of speech.

4.2.1. Novice Group Results

As previously stated, results from the Novice Group were removed from further analyses due to increased levels of inconsistency and unreliability. This suggests that perceptual analysis of voice is strongly dependent upon experience (Hillman, 2013). The 12 Master's degree students who participated in this stage of the project had not yet completed their coursework in Voice and Voice Disorders.

Additionally, nine of the students had not used the CAPE-V clinically, nor had they engaged with clients who presented with a voice disorder. The other three students had gained experience in voice disorders when they completed a single voice evaluation in the Center for Language, Speech and Hearing at the University of Massachusetts Amherst. They completed the CAPE-V as a portion of the voice evaluation. Overall, the group had no to limited experience working with clients who exhibited voice disorders. This was confirmed via verbal feedback from several of the students, who expressed that the samples were hard to judge, and that they were often uncertain of the task at hand, i.e., completing the perceptual ratings accurately.

4.2.2. Expert Group Results

The Expert Group produced more reliable and more consistent results than the Novice Group. This confirms that levels of experience play an important role in subjective analysis of voice. All of the expert judges had past experience in the use of the CAPE-V. Three of the judges had widespread clinical experience in using the CAPE-V, while the other three judges had substantial research background in implementing the CAPE-V.

It is important to note that three of the subjects with ASD were unable to complete the spontaneous speech tasks due to limited language levels. One child who was NTD did not complete the same tasks. A previous investigational study by this group of authors suggested that speech samples of less than ten seconds’ duration, e.g., vowel prolongations, did not provide sufficient information for perceptual analysis. Therefore, the judges only rated the speech samples obtained from the higher functioning children, who may have presented with less severe vocal qualities.

The judges’ also noted differences in nasality, although there was a lack of consensus regarding whether this was difference could be characterized as hyponasality or hypernasality. This suggests that the children with ASD demonstrated poor velar control, which in turn affects nasality. Poor velar control and differences in nasality are common characteristics of the motor speech disorder CAS.

4.2.2.1. Overall Severity

Both the ASD and the NTD group were judged to present with mild vocal impairments on all tasks. While singing Happy Birthday the children who were NTD obtained a slightly higher Overall Severity value than the ASD group; however, for all remaining tasks, values were higher for the ASD group. No differences reached a level of statistical significance. The lack of statistical significance between the groups may be due to the paucity of spontaneous speech samples obtained from the lower functioning children with ASD, who may have presented with more impaired vocal characteristics.

This suggests that the ASD group presented with a trend for slight vocal differences as compared to their NTD peers. Given that Cronbach's alpha values of 0.700 or greater were obtained for two ratings of Overall Severity on both narrative story telling tasks, it is plausible that the restricted content associated with the elicited speech tasks did not provide the judges with sufficient information from which to glean vocal differences.

4.2.2.2. Roughness

Although both of the groups were rated as presenting with mild levels of roughness, there was a consistent trend for decreased roughness to be perceived in the ASD group. This parameter was the most consistently rated parameter, as evidence by Cronbach's alpha values of 0.700 or greater on four out of five tasks (i.e., all but the Topic of Interest task). Although the numerical ratings varied among the judges, there was general agreement regarding the presence of roughness in all participants. A Swedish study by Sederholm (1995) suggested that approximately 6% of children who were 10 years of age presented with hoarseness.

4.2.2.3. Breathiness

As with roughness, all group averages reflected a mild level of impairment with respect to breathiness. Again, this feature was rated as being less notable for the ASD group in comparison to the NTD group. Boucher, Andrianopoulos, Velleman et al. (2009) suggested that breathiness was the most difficult task to judge in their study investigating the reliability of CAPE-V parameters amongst five experienced judges. This was upheld by this study, as breathiness was reliably calculated during Happy Birthday only. The consistency of a task appears to make judges more able to consistently hear the presence of this parameter.

4.2.2.4. Strain

Results regarding perceived strain were not as clear as those for other perceptual parameters. Happy Birthday, Story 2, and the Topic of Interest revealed higher levels of strain for the ASD group, while levels were lower for Story 1 and similar between groups for Counting. It is possible that strain was intermittently present among the samples, suggesting an overall inconsistency in vocal characteristics.

4.2.2.5. Pitch

Pitch was noted to be a difficult task for the judges to rate. Several judges provided verbal feedback that without the visual information obtained from looking at a child, e.g., their age, overall body stature, etc., it was difficult to determine if their pitch was atypical. For example, one of the youngest participants (a 4.5 year old female) had a particularly high pitch in relation to the other samples, but when her age and stature were taken into account, her pitch was commensurate. Additionally, one judge noted that the counting and singing tasks were harder to judge.

One judge consistently provided ratings of monopitch for both the ASD and the NTD children. No other judges provided similar ratings. As this judge was not blind to the purpose of the study, it is possible that this judge was fixated on this particular parameter. In addition, monopitch was not targeted during the training session. This suggests that the other judges may not have been primed to listen for this difference.

Despite these difficulties in rating pitch, a trend for a perceived increased pitch was present. This would be in agreement with the acoustic variables obtained from the

MDVP. However, since low levels of reliability were present for this perceptual parameter, correlations could not be calculated.

Prosody is a combination of pitch and loudness, but as one judge noted, it is also includes phrasing and structure. Thus, the judges qualitatively noted differences in prosody but consistent, numerical data were not available for further study. As with pitch, prosody was difficult to judge.

Deficits in prosodic output may be attributed to abnormalities in the corpus callosum, which could cause poor access to the left and right hemispheres (Bhatnagar, 2013). Other researchers suggest that prosodic deficits may emerge from deficits in the posterior temporal gyrus (Redcay, 2008), which incorporates both sensory and motor information, implicating the role of sensori-motor production in the production of prosody.

4.2.2.6. Loudness

As with pitch, loudness was difficult for many of the judges to determine. Judges noted differences in loudness that may have been due to differences in placement of the head-mounted microphone. As stated previously, three participants with ASD were unable to wear the head mounted microphone for the duration of the session due to sensory needs. During these times, which included all elicited and spontaneous speech samples, the principal investigator held the microphone approximately one inch from the participants’ mouths.

These methodological differences may have influenced the lack of statistically significant differences between the groups, as well as the lack of reliability from the judges. Nevertheless, a trend for increased loudness within the ASD group was present.

4.3. Acoustic to Perceptual Correlations

Little is known about the acoustic correlates of the perceptual parameters. Thus, it was a goal of this study to investigate these correlates further. The presence of an acoustic measure as a strong correlate on two or more correlations was interpreted as a likely contributor to one’s perception of that parameter.

4.3.1. Overall Severity

The Expert Judges’ perceptual ratings of Overall Severity were reliable for both stories. Two acoustic variables were strongly correlated with each of these two perceptual ratings. Both Absolute Jitter and Fundamental

Frequency Variation appeared to play a role in the listeners' perceptions of Overall Severity. Acoustic data revealed that Absolute Jitter was lower for the ASD group, while Fundamental Frequency Variation was higher. Thus, both decreased short-term pitch variability and increased long-term pitch variability contribute to perceptions of increased vocal severity.

4.3.1. Roughness

As previously stated, roughness was the most consistently rated parameter, achieving sufficient consistency on four of the five tasks (excepting the Topic of Interest task). These four ratings were correlated with a range of variables that most likely contributed to perceived roughness. The variable Smoothed Pitch Perturbation Quotient was significantly correlated with Roughness ratings on all four of these reliably rated tasks.

Additional measures of short- and long-term pitch variability also played a role in perceiving Roughness. These included Fundamental Frequency Variation, which was correlated with Roughness perceptions on three tasks, and both Absolute Jitter and Jitter Percent, which were each correlated with Roughness perceptions on two tasks. Past research has suggested that jitter may be a contributing factor to perceived roughness. This theory proved accurate, as ASD participants demonstrated both decreased levels of jitter and a decreased perception of roughness as compared to the NTD group.

Both sub-harmonic-related measures were correlated with Roughness perceptions on three tasks and the fundamental frequency measure Average Pitch Period was associated with the percept of Roughness on two tasks. Thus, these eight variables are likely to contribute to a judge’s perception of Roughness.

4.3.2. Breathiness

Acoustic correlates were available for the perception of breathiness on one task only. Thus, these results should be interpreted with caution until multiple correlations can be calculated to determine repeated influence of these variables.

A grouping of fundamental frequency variables, including Lowest Fundamental Frequency and Average Pitch Period, were strongly correlated to the perception of Breathiness. Additionally, measures of long-term pitch variability, including Fundamental Frequency Variation and the Smoothed Pitch Perturbation Quotient, also contributed to the listeners’ perceptions of Breathiness.

Other researchers have suggested that the Soft Phonation Index may be used as an indicator of breathiness; however, this was not found in this study.

4.3.3. Strain

One acoustic measure, Fundamental Frequency Variation, was found to be strongly correlated with perceived Strain for both tasks for which a relationship was calculated.

4.3.4. Pitch

Insufficient reliability for correlational analyses of pitch was present.

4.3.5. Loudness

Insufficient reliability for correlational analyses of loudness was present.

4.4. Summary

Children with ASD can be described as presenting with acoustic and perceptual features of voice that are consistently deviant, while also being consistently inconsistent in presentation of that deviance. Motor speech differences in this population may be difficult to diagnose as young children benefit from neurodevelopment and neuroplasticity and are constantly changing. Nevertheless, these difficulties support deficits in sensori-motor production.

The acoustic-perceptual and motor speech profile of autism, as determined by this study, is as follows:

- Significantly decreased Maximum Phonation Time.
- Lower formant values.
- Lower pitch values.
- Slower rate of speech, characterized by increased utterance, pause, and vowel durations.
- Reduced number of syllable repetitions in AMR and SMR tasks.
- Variable and/or inconsistent performance across tasks.
- A mildly deviant voice, further characterized by a mildly deviant level of roughness (reduced) and inconsistently increased strain, atypical production of prosody, and inconsistent nasality.

Table 60 contains a summary table of these factors, including the statistically significant tasks for each.

Based on the results of this empirical investigation, an acoustic-perceptual and motor speech profile for a child with an autism spectrum disorder can be determined by six tasks: prolongation of [f] and [a], articulation of AMRs and SMRs, counting from one to 10, and telling a story based on a wordless picture book. Together these six tasks can assist one in differentially diagnosing children with ASD from children who are NTD. These empirical findings support that intervention for children with ASD should not only focus on pragmatics, MLU, and vocabulary, as is often the case.

Rather, voice and motor speech treatment methodologies should be incorporated as appropriate to individuals with autism.

4.5. Methodological Issues

4.5.1. Limitations of the Study

The findings of this study are limited by several factors, the most notable of which is the small sample size. To effectively generalize the results of this study to all children with ASD, a larger sample should be studied.

The study may have also been affected by the composition of the NTD group. Although none of the children were diagnosed with a speech or language or other disorder, many of them struggled with the spontaneous speech tasks. It is plausible that motivation may have played a role in the performance of both groups of children.

Lastly, the paucity of data present for the more severely impaired children with ASD on the spontaneous speech tasks may have affected the perceptual ratings.

4.5.2. Suggestions for Future Research

The principal investigator would like to see a similar study performed on prelinguistic children. Sound productions, such as vocalization and cries could be studied to broaden the acoustic profile to include children without communication in any modality, or children without oral communication. This may also strengthen our understanding of children with limited oral communication who are not able to complete spontaneous language tasks, as seen in this study. As previously stated, approximately 50% of children with autism remain non-oral communicators throughout their lives (Paul, 1987; Seal & Bonvillian, 1997). Appropriate intervention – with potentially improved outcomes – depends critically on identifying the reason for their nonoral status (motor speech disorder versus other cause). An acoustic profile that could be obtained without meaningful speech would be essential to aiding in differential diagnosis of motor speech disorders in children with ASD.

TABLES

Table 1. Demographic Information

Participant Number	**Age**	**Sex**	**Diagnosis**
ASD1	9;6	Male	Autism
ASD2	9;11	Male	Autism + CAS
ASD3	12;2	Female	Autism
ASD4	7;2	Male	Autism
ASD5	5;4	Male	PDD-NOS
ASD6	4;9	Male	PDD-NOS
ASD7	6;9	Male	PDD-NOS
ASD8	8;8	Male	Asperger's
ASD9	12;9	Male	PDD-NOS
ASD10	4;8	Male	Asperger's
ASD11	9;11	Male	Autism
ASD12	10;3	Male	Asperger's
ASD13	10;8	Male	Autism
ASD14	4;5	Female	Autism + generalized motor
ASD15	9;6	Male	Autism
ASD Mean Age	**8 years 4 months (SD= 2 years 7 months)**		
NTD1	9;1	Male	Neurotypical
NTD2	9;3	Male	Neurotypical
NTD3	12;5	Female	Neurotypical
NTD4	7;5	Male	Neurotypical
NTD5	5;10	Male	Neurotypical
NTD6	5;5	Male	Neurotypical
NTD7	7;2	Female	Neurotypical
NTD8	8;0	Female	Neurotypical
NTD9	12;7	Male	Neurotypical
NTD10	4;11	Male	Neurotypical
NTD11	9;6	Female	Neurotypical
NTD12	10;0	Male	Neurotypical
NTD13	11;3	Male	Neurotypical
NTD14	4;5	Female	Neurotypical
NTD15	9;5	Male	Neurotypical
NTD Mean Age	**8 years 4 months (SD= 2 years 7 months)**		

Table 2. Stimulus Specific Measurements

Stimulus	**Measurements Performed**
[f] prolongation	maximum phonation time (sec)
[ɑ] prolongation	maximum phonation time (sec), voicing analysis
pea tea key	length of vowels (sec), length of pauses (sec), total duration (sec), voicing analysis; length of phrase final lengthening
[pʌ]	alternate motion rate (syllables/ second), total number of syllables produced
[tʌ]	alternate motion rate (syllables/ second), total number of syllables produced
[kʌ]	alternate motion rate (syllables/ second), total number of syllables produced
[pʌtʌkʌ]	sequential motor rate (syllables/ second), total number of syllables produced
Counting 1-10	length of pauses (sec), total duration (sec); perceptual analysis
Happy Birthday	voice analysis; perceptual analysis
Story Telling	voice analysis; perceptual analysis
Topic of Interest	voice analysis; perceptual analysis

Table 3. [f] Prolongation Statistics

Group	Mean Duration (sec)	Mean Individual variability within task (SD)	Mean Group variability within task (SD)	Significance
ASD	3.11	0.63	2.98	
NTD	5.00	1.30	2.59	
Mann-Whitney U				0.03*
Cohen's d				0.70

[Statistical analysis of prolongation of [f]]
* denotes statistically significant task ($p< 0.050$)
◆ denotes large effect size ($d >0.80$)

Table 4. Length of [f] Phoneme Prolongation (MPT)

ASD		**NTD**	
Subject	Mean time (sec)	Subject	Mean time (sec)
ASD1	1.98	NTD1	9.36
ASD2	0.58	NTD2	6.20
ASD3	1.32	NTD3	2.46
ASD4	0.79	NTD4	8.14
ASD5	0.63	NTD5	3.31
ASD6	1.53	NTD6	2.44
ASD7	11.01	NTD7	4.84
ASD8	8.28	NTD8	4.16
ASD9	11.40	NTD9	8.15
ASD10	2.22	NTD10	1.42
ASD11	5.95	NTD11	5.41
ASD12	8.12	NTD12	3.16
ASD13	5.69	NTD13	5.71
ASD14	0.45	NTD14	1.91
ASD15	8.10	NTD15	8.27

[Statistical analysis of prolongation of [f]]
* denotes statistically significant task ($p < 0.050$)

Table 5. [a] Prolongation Statistics

Group	**Mean Duration (sec)**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
ASD	4.51	1.22	5.00	
NTD	7.32	1.45	4.33	
Mann-Whitney U				0.08
Cohen's d				0.62

[Statistical analysis of prolongation of [a]]
* denotes statistically significant task (p< 0.050)
◆ denotes large effect size (d >0.80)

Table 6. Length of [a] Phoneme Prolongation

ASD		**NTD**	
Subject	Mean time (sec)	Subject	Mean time (sec)
ASD1	2.51	NTD1	14.36
ASD2	0.46	NTD2	6.31
ASD3	1.19	NTD3	1.65
ASD4	1.95	NTD4	5.53
ASD5	0.86	NTD5	8.43
ASD6	5.76	NTD6	10.85
ASD7	14.11	NTD7	5.96
ASD8	15.50	NTD8	5.69
ASD9	8.77	NTD9	7.79
ASD10	3.82	NTD10	6.35
ASD11	13.49	NTD11	4.91
ASD12	15.13	NTD12	3.68
ASD13	1.98	NTD13	16.3
ASD14	0.37	NTD14	0.77
ASD15	6.63	NTD15	11.29

[Statistical analysis of prolongation of [a]]
* denotes statistically significant task ($p< 0.050$)

Table 7. Duration of “pea tea key”

Task	**Group**	**Mean Duration (sec)**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
total	ASD	1.59	0.27	0.66	
	NTD	1.30	0.12	0.36	
	Mann-Whitney U				0.64
	Cohen’s d				0.58
pea-tea gap	ASD	0.25	0.13	0.20	
	NTD	0.23	0.04	0.11	
	Mann-Whitney U				0.72
	Cohen’s d				0.13
tea-key gap	ASD	0.20	0.06	0.11	
	NTD	0.24	0.05	0.11	
	Mann-Whitney U				0.64
	Cohen’s d				0.38
vowels					
[i] of “pea”	ASD	0.28	0.03	0.12	
	NTD	0.25	0.03	0.09	
	Mann-Whitney U				0.94
	Cohen’s d				0.30
[i] of “tea”	ASD	0.26	0.03	0.10	
	NTD	0.22	0.02	0.07	
	Mann-Whitney U				0.40
	Cohen’s d				0.37

[i] of “key”	ASD	0.27	0.05	0.08	
	NTD	0.16	0.04	0.06	
	Mann-Whitney U				0.00*
	Cohen’s d				1.63◆

[Durations of pauses, vowels and total repetitions of the phrase “pea tea key”]

* denotes statistically significant task (p< 0.050)

◆ denotes large effect size (d >0.80)

Table 8. Duration of Counting 1-10

Task	**Group**	**Mean Value (seconds)**	**Mean Individual Variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
Total	ASD	5.42		2.13	
	NTD	4.70		2.15	
	Mann-Whitney U				0.22
	Cohen's d				0.35
1-2 gap	ASD	0.23		0.27	
	NTD	0.19		0.25	
	Mann-Whitney U				0.38
	Cohen's d				0.20
2-3 gap	ASD	0.28		0.32	
	NTD	0.15		0.20	
	Mann-Whitney U				0.24
	Cohen's d				0.37
3-4 gap	ASD	0.25		0.23	
	NTD	0.18		0.23	
	Mann-Whitney U				0.32
	Cohen's d				0.32
4-5 gap	ASD	0.28		0.24	
	NTD	0.19		0.23	
	Mann-Whitney U				0.32
	Cohen's d				0.40
5-6 gap	ASD	0.20		0.29	
	NTD	0.15		0.20	
	Mann-Whitney U				0.86
	Cohen's d				0.21
6-7 gap	ASD	0.22		0.30	
	NTD	0.17		0.16	

	Mann-Whitney U				0.77
	Cohen's d				0.22
7-8 gap	ASD	0.21		0.21	
	NTD	0.15		0.20	
	Mann-Whitney U				0.22
	Cohen's d				0.30
8-9 gap	ASD	0.28		0.21	
	NTD	0.26		0.19	
	Mann-Whitney U				0.56
	Cohen's d				0.10
9-10 gap	ASD	0.16		0.20	
	NTD	0.16		0.17	
	Mann-Whitney U				0.82
	Cohen's d				0.00
Average gap	ASD	0.52	1.02	0.95	
	NTD	0.23	0.25	0.41	
	Mann-Whitney U				0.22
	Cohen's d				0.43

[Durations of pauses and total repetitions of counting one to 10]

* denotes statistically significant task ($p < 0.050$)

◆ denotes large effect size ($d > 0.80$)

Table 9. AMR and SMR Rate Statistics

Task	**Group**	**Mean Value (syllables /sec)**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
[pʌ]	ASD	4.57	0.44	0.79	
	NTD	7.74	0.42	0.62	
	Mann-Whitney U				0.18
	Cohen's d				4.69◆
[tʌ]	ASD	5.05	0.58	0.73	
	NTD	6.31	0.57	0.73	
	Mann-Whitney U				0.68
	Cohen's d				1.80◆
[kʌ]	ASD	4.13	0.34	1.06	
	NTD	3.74	0.26	0.66	
	Mann-Whitney U				0.34
	Cohen's d				0.47
[pʌtʌkʌ]	ASD	1.45	0.19	0.42	
	NTD	0.93	0.16	0.33	
	Mann-Whitney U				0.33
	Cohen's d				1.45◆

[AMR and SMR rates of production (syllables/ second) of [pʌ], [tʌ], [kʌ], and [pʌtʌkʌ]]

* denotes statistically significant task ($p < 0.050$)

◆ denotes large effect size ($d > 0.80$)

Table 10. AMR and SMR Number of Syllables Statistics

Task	**Group**	**Mean Value (syllables)**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
[pʌ]	ASD	14.50	2.61	10.09	
	NTD	25.67	4.45	13.88	
	Mann-Whitney U				0.02*
	Cohen's d				0.95◆
[tʌ]	ASD	14.59	2.72	10.08	
	NTD	26.19	5.18	5.75	
	Mann-Whitney U				0.01*
	Cohen's d				1.50◆
[kʌ]	ASD	13.94	3.15	9.46	
	NTD	22.29	4.17	11.06	
	Mann-Whitney U				0.02*
	Cohen's d				1.22◆
[pʌtʌkʌ]	ASD	4.59	1.08	2.37	
	NTD	7.67	1.60	4.23	
	Mann-Whitney U				0.07
	Cohen's d				0.92◆

[AMR and SMR number of syllables of [pʌ], [tʌ], [kʌ], and [pʌtʌkʌ]]

* denotes statistically significant task ($p < 0.050$)

◆ denotes large effect size ($d > 0.80$)

Table 11. AMR and SMR Duration Statistics

Task	**Group**	**Mean Value (sec)**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
[pʌ]	ASD	3.04	0.49	1.93	
	NTD	5.29	0.91	2.91	
	Mann-Whitney U				0.03*
	Cohen's d				0.93◆
[tʌ]	ASD	3.05	0.91	1.98	
	NTD	5.75	1.67	3.54	
	Mann-Whitney U				0.01*
	Cohen's d				0.96◆
[kʌ]	ASD	3.60	1.49	3.24	
	NTD	4.91	0.82	2.48	
	Mann-Whitney U				0.22
	Cohen's d				0.48
[pʌtʌkʌ]	ASD	3.32	1.10	1.42	
	NTD	4.82	1.10	3.07	
	Mann-Whitney U				0.60
	Cohen's d				0.64

[AMR and SMR length of production of [pʌ], [tʌ], [kʌ], and [pʌtʌkʌ]]

* denotes statistically significant task ($p < 0.050$)

◆ denotes large effect size ($d > 0.80$)

Table 12. [a] Prolongation Formant Statistics

Task	Group	Mean Value (Hz)	Mean Individual variability within task (SD)	Mean Group variability within task (SD)	Significance
F1	ASD	907.00	124.86	197.09	
	NTD	926.76	110.3	211.73	
	Mann-Whitney U				0.58
	Cohen’s d				0.03
F2	ASD	1710.28	209.61	276.40	
	NTD	1906.42	340.83	302.59	
	Mann-Whitney U				0.17
	Cohen’s d				0.70
F3	ASD	3259.97	279.31	220.54	
	NTD	3502.77	246.69	285.73	
	Mann-Whitney U				0.04*
	Cohen’s d				0.89◆

[Formant values of the vowel [a] prolongation as produced in isolation]

*denotes statistically significant task (p< 0.050)

◆ denotes large effect size (d >0.80)

Table 13. [i] Prolongation Formant Statistics

Task	**Group**	**Mean Value (Hz)**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
F1	ASD	373.37	51.15	75.14	
	NTD	522.05	279.28	391.02	
	Mann-Whitney U				0.43
	Cohen’s d				0.55
F2	ASD	2665.51	219.31	200.10	
	NTD	2808.18	186.58	391.91	
	Mann-Whitney U				0.15
	Cohen’s d				0.47
F3	ASD	3593.86	194.67	231.35	
	NTD	3758.88	261.45	323.03	
	Mann-Whitney U				0.10
	Cohen’s d				0.61

[Formant values for the vowel [i] as produced in isolation]
*denotes statistically significant task ($p< 0.050$)
◆ denotes large effect size ($d >0.80$)

Table 14. Formants of “pea tea key”

Task	Group	Mean Value (Hz)	Mean Individual variability within task (SD)	Mean Group variability within task (SD)	Significance
[i] of “pea”					
F1	ASD	577.04	224.35	566.49	
	NTD	368.88	41.03	60.11	
	Mann-Whitney U				0.90
	Cohen’s d				0.56
F2	ASD	2790.97	339.77	252.60	
	NTD	2990.24	182.52	318.89	
	Mann-Whitney U				0.05*
	Cohen’s d				0.71
F3	ASD	3511.21	356.80	625.13	
	NTD	3879.92	176.38	257.27	
	Mann-Whitney U				0.01*
	Cohen’s d				0.82◆
[i] of “tea”					
F1	ASD	524.98	192.96	456.33	
	NTD	398.47	58.75	72.00	
	Mann-Whitney U				0.32
	Cohen’s d				0.42
F2	ASD	2773.69	468.50	255.07	
	NTD	2998.21	214.24	229.37	
	Mann-Whitney U				0.01*

	Cohen’s d				0.96◆
F3	ASD	3443.20	368.85	739.04	
	NTD	3882.32	183.25	253.57	
	Mann-Whitney U				0.01*
	Cohen’s d				0.85◆
[i] of “key”					
F1	ASD	559.48	208.73	619.68	
	NTD	397.32	69.48	68.88	
	Mann-Whitney U				0.17
	Cohen’s d				0.40
F2	ASD	2821.43	391.80	234.63	
	NTD	2790.32	310.24	407.98	
	Mann-Whitney U				0.58
	Cohen’s d				0.10
F3	ASD	3582.10	362.29	596.96	
	NTD	3748.54	216.03	261.97	
	Mann-Whitney U				0.40
	Cohen’s d				0.38

[Formant values of the phrase “pea tea key”]
* denotes statistically significant task ($p < 0.050$)
◆ denotes large effect size ($d > 0.80$)

Table 15. Pitch Statistics ([a] and [i], in Isolation)

Task	**Group**	**Mean Value (Hz)**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
[a] pitch	ASD	203.41	18.23	26.71	
	NTD	204.28	13.02	29.24	
	Mann-Whitney U				0.94
	Cohen's d				0.03
[i] pitch	ASD	188.68	13.09	20.22	
	NTD	203.33	11.18	20.97	
	Mann-Whitney U				0.04*
	Cohen's d				0.74

[Pitch values of the vowels [a] and [i]]
* denotes statistically significant task ($p< 0.050$)
◆ denotes large effect size ($d >0.80$)

Table 16. Pitch of “pea tea key”

Task	**Group**	**Mean Value (Hz)**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
[i] of “pea”	ASD	197.51	29.15	23.74	
	NTD	206.18	30.87	22.39	
	Mann-Whitney U				0.11
	Cohen’s d				0.39
[i] of “tea”	ASD	203.83	37.49	23.73	
	NTD	212.25	21.75	24.46	
	Mann-Whitney U				0.08
	Cohen’s d				0.36
[i] of “key”	ASD	196.56	23.91	21.46	
	NTD	188.29	36.04	35.00	
	Mann-Whitney U				0.72
	Cohen’s d				0.29

[Pitch values of the phrase “pea tea key”]
* denotes statistically significant task ($p< 0.050$)
◆ denotes large effect size ($d >0.80$)

Table 17. Fundamental Frequency Measurements ([a] and [i])

Task	**Group**	**Mean Value**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
[a]					
Mean Average Fundamental Frequency (Hz)	ASD	287.67	14.79	62.00	
	NTD	262.05	8.63	44.87	
	Mann-Whitney U				0.49
	Cohen’s d				0.49
Mean of Mean Fundamental Frequency (Hz)	ASD	289.32	16.21	60.00	
	NTD	256.52	18.36	53.40	
	Mann-Whitney U				0.37
	Cohen’s d				0.60
Mean Average Pitch Period (ms)	ASD	3.62	0.13	0.72	
	NTD	3.93	0.12	0.67	
	Mann-Whitney U				0.68
	Cohen’s d				0.46
Mean Highest Fundamental Frequency (Hz)	ASD	288.65	35.00	80.44	
	NTD	281.45	15.30	48.99	
	Mann-Whitney U				0.68
	Cohen’s d				0.11
Mean Lowest Fundamental Frequency (Hz)	ASD	253.18	19.32	59.03	
	NTD	238.83	13.49	39.47	
	Mann-Whitney U				0.79
	Cohen’s d				0.30
Mean Standard Deviation of f0 (Hz)	ASD	10.38	3.59	10.42	
	NTD	6.14	2.89	4.18	
	Mann-Whitney U				0.30
	Cohen’s d				0.55
Mean Phonatory f0	ASD	4.97	1.46	1.97	
	NTD	3.83	1.38	1.59	1.59

Range in Semi-Tones	Mann-Whitney U		1.33	1.00	
	Cohen's d		1.81	1.29	0.66
[i]					
Mean of Average Fundamental Frequency (Hz)	ASD	300.23	14.19	61.27	
	NTD	270.46	9.07	42.40	
	Mann-Whitney U				0.52
	Cohen's d				0.58
Mean of Mean Fundamental Frequency (Hz)	ASD	295.49	12.66	57.77	
	NTD	269.83	8.55	42.72	
	Mann-Whitney U				0.58
	Cohen's d				0.52
Mean Average Pitch Period (ms)	ASD	3.56	0.18	0.63	
	NTD	3.86	0.24	0.65	
	Mann-Whitney U				0.32
	Cohen's d				0.49
Mean Highest Fundamental Frequency (Hz)	ASD	330.99	19.44	81.47	
	NTD	289.79	11.24	50.34	
	Mann-Whitney U				0.52
	Cohen's d				0.63
Mean Lowest Fundamental Frequency (Hz)	ASD	261.29	15.81	48.09	
	NTD	251.51	15.56	37.17	
	Mann-Whitney U				0.79
	Cohen's d				0.24
Mean Standard Deviation of f0 (Hz)	ASD	13.40	1.67	14.69	
	NTD	5.29	1.63	2.27	
	Mann-Whitney U				0.17
	Cohen's d				0.80◆
Mean Phonatory f0	ASD	4.96	0.83	1.65	
	NTD	3.32	1.02	0.93	

Range in Semi-Tones	Mann-Whitney U				0.17
	Cohen's d				1.27◆

[Fundamental Frequency Measurements of the vowels [a] and [i]]

* denotes statistically significant task ($p < 0.050$)

◆ denotes large effect size ($d > 0.80$)

Table 18. Fundamental Frequency Measurements (Elicited Speech Tasks)

Task	**Group**	**Mean Value**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
Counting					
Average Fundamental Frequency (Hz)	ASD	270.13		60.03	
	NTD	234.75		42.49	
	Mann-Whitney U				0.26
	Cohen's d				0.72
Mean Fundamental Frequency (Hz)	ASD	262.63		53.06	
	NTD	230.30		45.03	
	Mann-Whitney U				0.26
	Cohen's d				0.68
Average Pitch Period (ms)	ASD	3.93		0.72	
	NTD	4.51		0.95	
	Mann-Whitney U				0.26
	Cohen's d				0.72
Highest Fundamental Frequency (Hz)	ASD	379.96		112.63	
	NTD	314.44		79.85	
	Mann-Whitney U				0.23
	Cohen's d				0.71
Lowest Fundamental Frequency (Hz)	ASD	164.19		57.39	
	NTD	162.72		56.49	
	Mann-Whitney U				0.97
	Cohen's d				0.03
Standard Deviation of f0 (Hz)	ASD	47.33		44.77	
	NTD	29.96		20.87	
	Mann-Whitney U				0.54
	Cohen's				0.53

	d				
Phonatory f0 Range in Semi-Tones	ASD	15.86		8.61	
	NTD	13.12		4.53	
	Mann-Whitney U				0.59
	Cohen's d				0.42
Happy Birthday					
Average Fundamental Frequency (Hz)	ASD	328.54		71.79	
	NTD	255.50		42.87	
	Mann-Whitney U				0.03*
	Cohen's d				1.32◆
Mean Fundamental Frequency (Hz)	ASD	320.18		70.72	
	NTD	259.21		63.00	
	Mann-Whitney U				0.09
	Cohen's d				0.96◆
Average Pitch Period (ms)	ASD	3.25		0.66	
	NTD	4.14		0.82	
	Mann-Whitney U				0.04*
	Cohen's d				1.25◆
Highest Fundamental Frequency (Hz)	ASD	484.68		106.03	
	NTD	356.22		73.79	
	Mann-Whitney U				0.02*
	Cohen's d				1.49◆
Lowest Fundamental Frequency (Hz)	ASD	177.50		62.68	
	NTD	158.86		52.29	
	Mann-Whitney U				0.60
	Cohen's d				0.34
Standard Deviation of f0 (Hz)	ASD	54.20		10.95	
	NTD	42.22		16.35	
	Mann-Whitney U				0.07
	Cohen's				0.90◆

	d				
Phonatory f0 Range in Semi-Tones	ASD	19.00		4.54	
	NTD	15.50		4.99	
	Mann-Whitney U				0.08
	Cohen’s d				0.77

[Fundamental Frequency Measurements of the elicited speech tasks Counting and Happy Birthday]

* denotes statistically significant task ($p< 0.050$)

◆ denotes large effect size ($d >0.80$)

Table 19. Fundamental Frequency Measurements (Spontaneous Speech Tasks)

Task	**Group**	**Mean Value**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
Story 1					
Average Fundamental Frequency (Hz)	ASD	265.93		35.44	
	NTD	222.85		28.98	
	Mann-Whitney U				0.02*
	Cohen's d				1.40◆
Mean Fundamental Frequency (Hz)	ASD	259.81		33.13	
	NTD	222.13		33.56	
	Mann-Whitney U				0.03*
	Cohen's d				1.18◆
Average Pitch Period (ms)	ASD	3.91		0.51	
	NTD	4.59		0.66	
	Mann-Whitney U				0.04*
	Cohen's d				1.20◆
Highest Fundamental Frequency (Hz)	ASD	416.27		122.11	
	NTD	317.31		66.47	
	Mann-Whitney U				0.039*
	Cohen's d				1.07◆
Lowest Fundamental Frequency (Hz)	ASD	157.17		57.63	
	NTD	143.75		48.03	
	Mann-Whitney U				0.79
	Cohen's d				0.27
Standard Deviation of f0 (Hz)	ASD	41.77		21.84	
	NTD	24.78		16.93	
	Mann-Whitney				0.02*

	U				
	Cohen’s d				0.92◆
Phonatory f0 Range in Semi-Tones	ASD	18.25		8.15	
	NTD	15.25		4.16	
	Mann-Whitney U				0.38
	Cohen’s d				0.49
Story 2					
Average Fundamental Frequency (Hz)	ASD	260.41		48.29	
	NTD	226.28		30.11	
	Mann-Whitney U				0.12
	Cohen’s d				0.90◆
Mean Fundamental Frequency (Hz)	ASD	251.64		45.69	
	NTD	222.31		30.96	
	Mann-Whitney U				0.14
	Cohen’s d				0.79
Average Pitch Period (ms)	ASD	4.09		0.76	
	NTD	4.58		0.65	
	Mann-Whitney U				0.14
	Cohen’s d				0.73
Highest Fundamental Frequency (Hz)	ASD	436.41		122.21	
	NTD	339.18		78.37	
	Mann-Whitney U				0.04*
	Cohen’s d				1.00◆
Lowest Fundamental Frequency (Hz)	ASD	128.23		56.47	
	NTD	143.06		62.43	
	Mann-Whitney U				0.62
	Cohen’s d				0.26
Standard Deviation of f0 (Hz)	ASD	51.20		18.88	
	NTD	29.48		23.90	
	Mann-Whitney				0.03*

	U				
	Cohen's d				1.05◆
Phonatory f0 Range in Semi-Tones	ASD	23.38		8.11	
	NTD	17.17		9.25	
	Mann-Whitney U				0.12
	Cohen's d				0.74
Topic of Interest					
Average Fundamental Frequency (Hz)	ASD	313.55		81.59	
	NTD	233.84		38.00	
	Mann-Whitney U				0.01*
	Cohen's d				1.39◆
Mean Fundamental Frequency (Hz)	ASD	302.99		76.69	
	NTD	230.10		38.19	
	Mann-Whitney U				0.02*
	Cohen's d				1.33◆
Average Pitch Period (ms)	ASD	3.47		0.82	
	NTD	4.56		0.73	
	Mann-Whitney U				0.02*
	Cohen's d				1.49◆
Highest Fundamental Frequency (Hz)	ASD	487.16		130.33	
	NTD	355.43		100.05	
	Mann-Whitney U				0.05*
	Cohen's d				1.22◆
Lowest Fundamental Frequency (Hz)	ASD	167.43		44.89	
	NTD	136.51		60.23	
	Mann-Whitney U				0.26
	Cohen's d				0.60
Standard Deviation of f0 (Hz)	ASD	59.33		30.36	
	NTD	29.17		13.56	
	Mann-Whitney				0.01*

	U				
	Cohen’s d				1.43◆
Phonatory f0 Range in Semi-Tones	ASD	19.57		5.56	
	NTD	18.42		8.58	
	Mann-Whitney U				0.59
	Cohen’s d				0.16

[Fundamental Frequency Measurements of the spontaneous speech tasks Story 1, Story 2, and Topic of Interest]

* denotes statistically significant task ($p < 0.050$)

◆ denotes large effect size ($d > 0.80$)

Table 20. Short- and Long-Term Frequency Perturbation Measurements ([a] and [i])

Task	**Group**	**Mean Value**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
[a]					
Mean Absolute Jitter (us)	ASD	53.00	19.05	32.79	
	NTD	64.51	18.37	33.52	
	Mann-Whitney U				0.68
	Cohen's d				0.36
Mean Jitter Percent (%)	ASD	1.42	0.50	0.76	
	NTD	1.67	0.46	0.90	
	Mann-Whitney U				0.79
	Cohen's d				0.31
Mean Relative Average Perturbation Quotient (%)	ASD	0.86	0.34	0.46	
	NTD	1.01	0.28	0.55	
	Mann-Whitney U				0.79
	Cohen's d				0.31
Mean Pitch Perturbation Quotient (%)	ASD	0.85	0.85	0.29	
	NTD	0.99	0.27	0.54	
	Mann-Whitney U				0.79
	Cohen's d				0.33
Mean Smoothed Pitch Perturbation Quotient (%)	ASD	1.18	0.47	0.86	
	NTD	1.07	0.30	0.45	
	Mann-Whitney U				0.91
	Cohen's d				0.17
Mean Fundamental Frequency Variation (%)	ASD	3.50	1.17	3.15	
	NTD	2.29	1.03	1.40	
	Mann-Whitney U				0.49
	Cohen's				0.51

	d				
[i]					
Mean Absolute Jitter (us)	ASD	60.07	18.75	25.27	
	NTD	55.96	19.93	28.34	
	Mann-Whitney U				0.91
	Cohen's d				0.16
Mean Jitter Percent (%)	ASD	1.74	0.49	0.76	
	NTD	1.52	0.54	0.83	
	Mann-Whitney U				0.76
	Cohen's d				0.29
Mean Relative Average Perturbation Quotient (%)	ASD	1.02	0.30	0.48	
	NTD	0.90	0.32	0.50	
	Mann-Whitney U				0.87
	Cohen's d				0.25
Mean Pitch Perturbation Quotient (%)	ASD	0.96	0.28	0.45	
	NTD	0.89	0.32	0.51	
	Mann-Whitney U				0.94
	Cohen's d				0.15
Mean Smoothed Pitch Perturbation Quotient (%)	ASD	1.41	0.32	0.90	
	NTD	0.96	0.28	0.46	
	Mann-Whitney U				0.55
	Cohen's d				0.65
Mean Fundamental Frequency Variation (%)	ASD	4.16	0.62	3.42	
	NTD	1.93	0.61	0.66	
	Mann-Whitney U				0.18
	Cohen's d				0.94◆

[Short- and long-term frequency perturbation measurements of the vowels [a] and [i]]

*denotes statistically significant task ($p<0.050$)

◆ denotes large effect size ($d >0.80$)

Table 21. Short- and Long-Term Frequency Perturbation Measurements (Elicited Speech Tasks)

Task	**Group**	**Mean Value**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
Counting					
Absolute Jitter (us)	ASD	103.09		25.20	
	NTD	156.65		57.28	
	Mann-Whitney U				0.01*
	Cohen's d				1.23◆
Jitter Percent (%)	ASD	2.68		0.70	
	NTD	3.43		0.78	
	Mann-Whitney U				0.08
	Cohen's d				1.05◆
Relative Average Perturbation Quotient (%)	ASD	1.54		0.41	
	NTD	2.03		0.54	
	Mann-Whitney U				0.05*
	Cohen's d				1.05◆
Pitch Perturbation Quotient (%)	ASD	1.71		0.58	
	NTD	2.22		0.81	
	Mann-Whitney U				0.17
	Cohen's d				0.75
Smoothed Pitch Perturbation Quotient (%)	ASD	6.77		4.81	
	NTD	4.98		3.87	
	Mann-Whitney U				0.33
	Cohen's d				0.43
Fundamental Frequency Variation (%)	ASD	16.13		11.61	
	NTD	13.79		11.41	
	Mann-Whitney U				0.59
	Cohen's				0.21

	d				
Happy Birthday					
Absolute Jitter (us)	ASD	72.53		18.85	
	NTD	111.01		28.02	
	Mann-Whitney U				0.01*
	Cohen’s d				1.68◆
Jitter Percent (%)	ASD	2.28		0.60	
	NTD	2.70		0.59	
	Mann-Whitney U				0.13
	Cohen’s d				0.74
Relative Average Perturbation Quotient (%)	ASD	1.36		0.37	
	NTD	1.59		0.35	
	Mann-Whitney U				0.19
	Cohen’s d				0.67
Pitch Perturbation Quotient (%)	ASD	1.40		0.34	
	NTD	1.68		0.35	
	Mann-Whitney U				0.09
	Cohen’s d				0.85◆
Smoothed Pitch Perturbation Quotient (%)	ASD	3.57		1.07	
	NTD	4.66		1.67	
	Mann-Whitney U				0.32
	Cohen’s d				0.81◆
Fundamental Frequency Variation (%)	ASD	16.55		2.77	
	NTD	16.98		7.72	
	Mann-Whitney U				0.74
	Cohen’s d				0.08

[Short- and long-term frequency perturbation measurements of the elicited speech tasks “Counting” and “Happy Birthday”]]
*denotes statistically significant task (p<0.050)
◆ denotes large effect size (d >0.80)

Table 22. Short- and Long-Term Frequency Perturbation Measurements (Spontaneous Speech Tasks)

Task	**Group**	**Mean Value**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
Story 1					
Absolute Jitter (us)	ASD	111.90		37.26	
	NTD	158.60		89.87	
	Mann-Whitney U				0.18
	Cohen's d				0.70
Jitter Percent (%)	ASD	3.47		1.68	
	NTD	3.40		1.53	
	Mann-Whitney U				0.79
	Cohen's d				0.05
Relative Average Perturbation Quotient (%)	ASD	1.65		0.51	
	NTD	1.98		0.95	
	Mann-Whitney U				0.68
	Cohen's d				0.45
Pitch Perturbation Quotient (%)	ASD	1.92		0.55	
	NTD	4.36		7.57	
	Mann-Whitney U				1.00
	Cohen's d				0.46
Smoothed Pitch Perturbation Quotient (%)	ASD	5.79		2.05	
	NTD	5.81		7.13	
	Mann-Whitney U				0.07
	Cohen's d				0.00
Fundamental Frequency Variation (%)	ASD	15.52		6.60	
	NTD	11.51		8.84	
	Mann-Whitney U				0.07
	Cohen's				0.53

	d				
Story 2					
Absolute Jitter (us)	ASD	120.05		28.62	
	NTD	141.59		57.58	
	Mann-Whitney U				0.57
	Cohen’s d				0.49
Jitter Percent (%)	ASD	2.97		0.63	
	NTD	3.08		1.16	
	Mann-Whitney U				0.85
	Cohen’s d				0.12
Relative Average Perturbation Quotient (%)	ASD	1.69		0.37	
	NTD	1.69		0.81	
	Mann-Whitney U				1.00
	Cohen’s d				0.00
Pitch Perturbation Quotient (%)	ASD	1.95		0.50	
	NTD	1.98		0.80	
	Mann-Whitney U				0.79
	Cohen’s d				0.05
Smoothed Pitch Perturbation Quotient (%)	ASD	5.24		1.65	
	NTD	5.22		3.85	
	Mann-Whitney U				0.43
	Cohen’s d				0.01
Fundamental Frequency Variation (%)	ASD	19.73		6.36	
	NTD	13.48		10.49	
	Mann-Whitney U				0.06
	Cohen’s d				0.75
Topic of Interest					
Absolute Jitter (us)	ASD	94.30		21.46	
	NTD	133.61		32.40	
	Mann-Whitney U				0.01*

	Cohen's d				1.46◆
Jitter Percent (%)	ASD	2.76		0.50	
	NTD	3.02		0.75	
	Mann-Whitney U				0.97
	Cohen's d				0.42
Relative Average Perturbation Quotient (%)	ASD	1.58		0.30	
	NTD	1.77		0.45	
	Mann-Whitney U				0.90
	Cohen's d				0.51
Pitch Perturbation Quotient (%)	ASD	1.82		0.38	
	NTD	1.99		0.59	
	Mann-Whitney U				0.77
	Cohen's d				0.35
Smoothed Pitch Perturbation Quotient (%)	ASD	5.42		1.80	
	NTD	4.86		2.40	
	Mann-Whitney U				0.65
	Cohen's d				0.27
Fundamental Frequency Variation (%)	ASD	18.37		4.55	
	NTD	11.96		4.92	
	Mann-Whitney U				0.02*
	Cohen's d				1.41◆

[Short- and long-term frequency perturbation measurements of the spontaneous speech tasks Story 1, Story 2, and Topic of Interest]]

*denotes statistically significant task ($p<0.050$)

◆ denotes large effect size ($d > 0.80$)

Table 23. Short- and Long-Term Amplitude Perturbation Measurements ([a] and [i])

Task	**Group**	**Mean Value**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
[a]					
Mean Shimmer in dB	ASD	0.40	0.09	0.19	
	NTD	0.39	0.08	0.13	
	Mann-Whitney U				0.87
	Cohen's d				0.06
Mean Shimmer in Percent	ASD	4.35	1.03	2.03	
	NTD	4.35	0.89	1.34	
	Mann-Whitney U				0.87
	Cohen's d				0.00
Mean Amplitude Perturbation Quotient (%)	ASD	3.22	3.22	0.84	
	NTD	2.95	0.62	0.80	
	Mann-Whitney U				1.00
	Cohen's d				0.34
Mean Smoothed Amplitude Perturbation Quotient	ASD	8.10	4.02	8.12	
	NTD	4.61	1.45	1.36	
	Mann-Whitney U				0.65
	Cohen's d				0.62
Mean Peak-to-Peak Amplitude Variation (%)	ASD	24.33	7.94	16.02	
	NTD	14.76	3.44	7.71	
	Mann-Whitney U				0.32
	Cohen's d				0.79
[i]					
Mean Shimmer in dB	ASD	0.39	0.09	0.21	
	NTD	0.28	0.06	0.12	
	Mann-Whitney				0.58

	U				
	Cohen’s d				0.67
Mean Shimmer in Percent	ASD	3.74	0.82	1.98	
	NTD	3.03	0.73	1.25	
	Mann-Whitney U				0.68
	Cohen’s d				0.44
Mean Amplitude Perturbation Quotient (%)	ASD	2.63	0.66	1.53	
	NTD	2.09	0.36	0.85	
	Mann-Whitney U				0.68
	Cohen’s d				0.45
Mean Smoothed Amplitude Perturbation Quotient	ASD	6.15	0.89	4.67	
	NTD	3.18	0.75	1.75	
	Mann-Whitney U				0.11
	Cohen’s d				0.87◆
Mean Peak-to-Peak Amplitude Variation (%)	ASD	24.21	6.57	9.13	
	NTD	13.14	3.15	5.03	
	Mann-Whitney U				0.18
	Cohen’s d				1.55◆

[Short- and long-term amplitude perturbation measurements of the vowels [a] and [i]]

*denotes statistically significant task (p<0.050)

◆ denotes large effect size (d >0.80)

Table 24. Short- and Long-Term Amplitude Perturbation Measurements (Elicited Speech Tasks)

Task	**Group**	**Mean Value**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
Counting					
Shimmer in dB	ASD	0.72		0.21	
	NTD	0.87		0.26	
	Mann-Whitney U				0.20
	Cohen's d				0.66
Shimmer in Percent	ASD	6.75		1.86	
	NTD	7.87		1.93	
	Mann-Whitney U				0.08
	Cohen's d				0.62
Amplitude Perturbation Quotient (%)	ASD	7.62		3.40	
	NTD	8.14		2.30	
	Mann-Whitney U				0.12
	Cohen's d				0.19
Smoothed Amplitude Perturbation Quotient	ASD	22.58		6.86	
	NTD	25.42		6.29	
	Mann-Whitney U				0.38
	Cohen's d				0.45
Peak-to-Peak Amplitude Variation (%)	ASD	48.01		13.95	
	NTD	42.55		10.86	
	Mann-Whitney U				0.48
	Cohen's d				0.46
Happy Birthday					
Shimmer in dB	ASD	0.53		0.11	
	NTD	0.68		0.20	
	Mann-Whitney				0.11

	U				
	Cohen’s d				0.96◆
Shimmer in Percent	ASD	5.06		1.32	
	NTD	5.83		1.20	
	Mann-Whitney U				0.35
	Cohen’s d				0.64
Amplitude Perturbation Quotient (%)	ASD	4.75		1.32	
	NTD	6.12		2.06	
	Mann-Whitney U				0.19
	Cohen’s d				0.82◆
Smoothed Amplitude Perturbation Quotient	ASD	14.14		5.78	
	NTD	16.97		5.00	
	Mann-Whitney U				0.32
	Cohen’s d				0.55
Peak-to-Peak Amplitude Variation (%)	ASD	36.33		7.62	
	NTD	42.23		4.87	
	Mann-Whitney U				0.07
	Cohen’s d				0.98◆

[Short- and long-term amplitude perturbation measurements of the elicited speech tasks “Counting” and “Happy Birthday”]
*denotes statistically significant task (p<0.050)
◆ denotes large effect size (d >0.80)

Table 25. Short- and Long-Term Amplitude Perturbation Measurements (Spontaneous Speech Tasks)

Task	**Group**	**Mean Value**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
Story 1					
Shimmer in dB	ASD	0.75		0.26	
	NTD	0.77		0.13	
	Mann-Whitney U				1.00
	Cohen's d				0.10
Shimmer in Percent	ASD	7.36		2.31	
	NTD	7.74		1.23	
	Mann-Whitney U				0.68
	Cohen's d				0.22
Amplitude Perturbation Quotient (%)	ASD	7.91		2.50	
	NTD	8.04		1.35	
	Mann-Whitney U				0.79
	Cohen's d				0.07
Smoothed Amplitude Perturbation Quotient	ASD	22.68		7.57	
	NTD	20.10		3.42	
	Mann-Whitney U				0.57
	Cohen's d				0.47
Peak-to-Peak Amplitude Variation (%)	ASD	76.61		102.75	
	NTD	37.38		10.82	
	Mann-Whitney U				0.18
	Cohen's d				0.58
Story 2					
Shimmer in dB	ASD	0.82		0.09	
	NTD	0.78		0.22	
	Mann-Whitney				0.79

	U				
	Cohen’s d				0.24
Shimmer in Percent	ASD	7.69		0.98	
	NTD	7.72		1.84	
	Mann-Whitney U				0.85
	Cohen’s d				0.02
Amplitude Perturbation Quotient (%)	ASD	8.40		1.17	
	NTD	7.97		2.12	
	Mann-Whitney U				0.57
	Cohen’s d				0.26
Smoothed Amplitude Perturbation Quotient	ASD	26.37		6.32	
	NTD	20.21		5.61	
	Mann-Whitney U				0.05*
	Cohen’s d				1.08◆
Peak-to-Peak Amplitude Variation (%)	ASD	54.36		7.43	
	NTD	39.28		10.01	
	Mann-Whitney U				0.00*
	Cohen’s d				1.78◆
Topic of Interest					
Shimmer in dB	ASD	0.71		0.12	
	NTD	0.72		0.20	
	Mann-Whitney U				1.00
	Cohen’s d				0.60
Shimmer in Percent	ASD	6.80		1.18	
	NTD	6.98		1.86	
	Mann-Whitney U				1.00
	Cohen’s d				0.12
Amplitude Perturbation Quotient (%)	ASD	7.51		1.29	
	NTD	7.40		2.38	
	Mann-Whitney				0.71

	U				
	Cohen's d				0.06
Smoothed Amplitude Perturbation Quotient	ASD	21.57		5.32	
	NTD	19.42		6.31	
	Mann-Whitney U				0.65
	Cohen's d				0.38
Peak-to-Peak Amplitude Variation (%)	ASD	46.27		9.21	
	NTD	40.80		10.98	
	Mann-Whitney U				0.34
	Cohen's d				0.56

[Short- and long-term amplitude perturbation measurements of the spontaneous speech tasks Story 1, Story 2 and Topic of Interest]
*denotes statistically significant task ($p<0.050$)
◆ denotes large effect size ($d >0.80$)

Table 26. Noise-Related Measurements ([a] and [i])

Task	**Group**	**Mean Value**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
[a]					
Mean Noise to Harmonics Ratio	ASD	0.14	0.02	0.04	
	NTD	0.13	0.02	0.02	
	Mann-Whitney U				0.72
	Cohen's d				0.33
Mean Voice Turbulence Index	ASD	0.04	0.01	0.01	
	NTD	0.05	0.01	0.02	
	Mann-Whitney U				1.00
	Cohen's d				0.65
Mean Soft Phonation Index	ASD	12.44	5.86	9.36	
	NTD	14.01	2.86	9.01	
	Mann-Whitney U				0.94
	Cohen's d				0.18
[i]					
Mean Noise to Harmonics Ratio	ASD	0.14	0.02	0.04	
	NTD	0.14	0.02	0.03	
	Mann-Whitney U				0.55
	Cohen's d				0.00
Mean Voice Turbulence Index	ASD	0.05	0.02	0.03	
	NTD	0.04	0.01	0.01	
	Mann-Whitney U				0.61
	Cohen's d				0.46
Mean Soft Phonation Index	ASD	19.63	4.62	13.67	
	NTD	17.12	3.38	8.19	
	Mann-Whitney U				1.00
	Cohen's d				0.23

[Noise-related measurements of the vowels [a] and [i]]
*denotes statistically significant task ($p<0.050$)
◆ denotes large effect size ($d >0.80$)

Table 27. Noise-Related Measurements (Elicited Speech Tasks)

Task	Group	Mean Value	Mean Individual variability within task (SD)	Mean Group variability within task (SD)	Significance
Counting					
Noise to Harmonics Ratio	ASD	0.25		0.09	
	NTD	0.24		0.06	
	Mann-Whitney U				1.00
	Cohen's d				0.14
Voice Turbulence Index	ASD	0.09		0.07	
	NTD	0.14		0.17	
	Mann-Whitney U				0.48
	Cohen's d				0.39
Soft Phonation Index	ASD	21.82		9.09	
	NTD	21.68		6.76	
	Mann-Whitney U				1.00
	Cohen's d				0.02
Happy Birthday					
Noise to Harmonics Ratio	ASD	0.19		0.04	
	NTD	0.22		0.03	
	Mann-Whitney U				0.27
	Cohen's d				0.90◆
Voice Turbulence Index	ASD	0.09		0.07	
	NTD	0.12		0.06	
	Mann-Whitney U				0.13
	Cohen's d				0.49
Soft Phonation Index	ASD	17.42		10.94	
	NTD	21.01		5.24	
	Mann-Whitney				0.19

	U				
	Cohen’s d				0.45

[Noise-related measurements of the elicited speech tasks “Counting” and “Happy Birthday”]

*denotes statistically significant task ($p<0.050$)

◆ denotes large effect size ($d >0.80$)

Table 28. Noise-Related Measurements (Spontaneous Speech Tasks)

Task	**Group**	**Mean Value**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
Story 1					
Noise to Harmonics Ratio	ASD	0.28		0.13	
	NTD	0.27		0.04	
	Mann-Whitney U				1.00
	Cohen's d				0.11
Voice Turbulence Index	ASD	0.18		0.21	
	NTD	0.12		0.16	
	Mann-Whitney U				0.52
	Cohen's d				0.34
Soft Phonation Index	ASD	19.39		9.12	
	NTD	21.88		5.79	
	Mann-Whitney U				0.31
	Cohen's d				0.34
Story 2					
Noise to Harmonics Ratio	ASD	0.25		0.06	
	NTD	0.25		0.05	
	Mann-Whitney U				0.52
	Cohen's d				0.00
Voice Turbulence Index	ASD	0.14		0.12	
	NTD	0.19		0.21	
	Mann-Whitney U				0.91
	Cohen's d				0.30
Soft Phonation Index	ASD	19.60		8.54	
	NTD	20.05		6.02	
	Mann-Whitney				0.31

	U				
	Cohen's d				0.06
Topic of Interest					
Noise to Harmonics Ratio	ASD	0.27		0.07	
	NTD	0.25		0.07	
	Mann-Whitney U				0.14
	Cohen's d				0.30
Voice Turbulence Index	ASD	0.20		0.14	
	NTD	0.31		0.49	
	Mann-Whitney U				0.77
	Cohen's d				0.30
Soft Phonation Index	ASD	15.94		10.14	
	NTD	25.27		11.78	
	Mann-Whitney U				0.04*
	Cohen's d				0.88◆

[Noise-related measurements of the spontaneous speech tasks Story 1, Story 2, and Topic of Interest]

*denotes statistically significant task ($p<0.050$)

◆ denotes large effect size ($d >0.80$)

Table 29. Tremor-Related Measurements ([a] and [i] Prolongation)

Task	**Group**	**Mean Value**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
[a]	No values calculated by MDVP				
Mean Amplitude Tremor Frequency	ASD				
	NTD				
	Mann-Whitney U				
	Cohen's d				
Mean f0 Tremor Intensity Index (%)	ASD				
	NTD				
	Mann-Whitney U				
	Cohen's d				
Mean Amplitude Tremor Intensity Index	ASD				
	NTD				
	Mann-Whitney U				
	Cohen's d				
[i]	Values inconsistently calculated by MDVP				
Mean Amplitude Tremor Frequency	ASD				
	NTD				
	Mann-Whitney U				
	Cohen's d				
Mean f0 Tremor Intensity Index (%)	ASD				
	NTD				
	Mann-Whitney U				
	Cohen's d				
Mean Amplitude Tremor Intensity Index	ASD				
	NTD				
	Mann-Whitney U				
	Cohen's d				

[Tremor-related measurements of the vowels [a] and [i]]
*denotes statistically significant task (p<0.050)
◆ denotes large effect size (d >0.80)

Table 30. Tremor-Related Measurements (Elicited Speech Tasks)

Task	**Group**	**Mean Value**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
Counting					
Amplitude Tremor Frequency	ASD	3.56		1.41	
	NTD	2.99		0.71	
	Mann-Whitney U				0.56
	Cohen's d				0.55
f0 Tremor Intensity Index (%)	ASD	1.72		1.54	
	NTD	2.87		3.02	
	Mann-Whitney U				0.75
	Cohen's d				0.49
Amplitude Tremor Intensity Index	ASD	6.48		3.68	
	NTD	10.76		8.46	
	Mann-Whitney U				0.44
	Cohen's d				0.66
Happy Birthday					
Amplitude Tremor Frequency	ASD	4.30		2.17	
	NTD	4.19		2.01	
	Mann-Whitney U				1.00
	Cohen's d				0.06
f0 Tremor Intensity Index (%)	ASD	1.83		2.03	
	NTD	2.37		2.65	
	Mann-Whitney U				0.70
	Cohen's d				0.24
Amplitude Tremor Intensity Index	ASD	6.36		5.23	
	NTD	7.34		2.50	
	Mann-Whitney				0.42

	U				
	Cohen's d				0.26

[Tremor-related measurements of the elicited speech tasks "Counting" and "Happy Birthday"]

*denotes statistically significant task (p<0.050)

◆ denotes large effect size (d >0.80)

Table 31. Tremor-Related Measurements (Spontaneous Speech Tasks)

Task	**Group**	**Mean Value**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
Story 1					
Amplitude Tremor Frequency	ASD	4.37		4.37	
	NTD	1.77		1.42	
	Mann-Whitney U				0.57
	Cohen's d				0.85◆
f0 Tremor Intensity Index (%)	ASD	1.40		0.95	
	NTD	0.90		0.42	
	Mann-Whitney U				0.24
	Cohen's d				0.72
Amplitude Tremor Intensity Index	ASD	4.28		2.89	
	NTD	3.98		2.27	
	Mann-Whitney U				0.73
	Cohen's d				0.12
Story 2					
Amplitude Tremor Frequency	ASD	3.87		3.87	
	NTD	4.37		2.55	
	Mann-Whitney U				0.71
	Cohen's d				0.16
f0 Tremor Intensity Index (%)	ASD	1.95		1.05	
	NTD	0.66		0.59	
	Mann-Whitney U				0.01*
	Cohen's d				1.61◆
Amplitude Tremor Intensity Index	ASD	5.64		1.89	
	NTD	3.88		1.82	
	Mann-Whitney				0.08

	U				
	Cohen's d				0.99◆
Topic of Interest					
Amplitude Tremor Frequency	ASD	3.69		1.95	
	NTD	3.94		1.47	
	Mann-Whitney U				0.68
	Cohen's d				0.16
f0 Tremor Intensity Index (%)	ASD	1.97		1.68	
	NTD	1.11		0.93	
	Mann-Whitney U				0.30
	Cohen's d				0.70
Amplitude Tremor Intensity Index	ASD	6.68		3.92	
	NTD	4.07		2.13	
	Mann-Whitney U				0.14
	Cohen's d				0.91◆

[Tremor-related measurements of the spontaneous speech tasks Story 1, Story 2, and Topic of Interest]

*denotes statistically significant task ($p<0.050$)

◆ denotes large effect size ($d >0.80$)

Table 32. Voice Break-Related Measurements ([a] and [i])

Task	**Group**	**Mean Value**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
[a]					
Mean Degree of Voice Breaks (%)	ASD	1.40	1.40	2.42	
	NTD	0.00	0.00	0.00	
	Mann-Whitney U				0.49
	Cohen's d				0.85◆
Mean Number of Voice Breaks	ASD	0.17	0.29	0.42	
	NTD	0.00	0.00	0.00	
	Mann-Whitney U				0.49
	Cohen's d				0.59
[i]					
Mean Degree of Voice Breaks (%)	ASD	0.00	0.00	0.00	
	NTD	0.00	0.00	0.00	
	Mann-Whitney U				1.00
	Cohen's d				0.00
Mean Number of Voice Breaks	ASD	0.00	0.00	0.00	
	NTD	0.00	0.00	0.00	
	Mann-Whitney U				1.00
	Cohen's d				0.00

[Voice break-related measurements of the vowels [a] and [i]]
*denotes statistically significant task ($p<0.050$)
◆ denotes large effect size ($d >0.80$)

Table 33. Voice Break-Related Measurements (Elicited Speech Tasks)

Task	Group	Mean Value	Mean Individual variability within task (SD)	Mean Group variability within task (SD)	Significance
Counting					
Degree of Voice Breaks (%)	ASD	54.12		17.56	
	NTD	57.20		15.64	
	Mann-Whitney U				0.65
	Cohen’s d				0.19
Number of Voice Breaks	ASD	9.71		0.95	
	NTD	9.25		2.09	
	Mann-Whitney U				0.77
	Cohen’s d				0.29
Happy Birthday					
Degree of Voice Breaks (%)	ASD	57.62		16.73	
	NTD	43.29		7.23	
	Mann-Whitney U				0.06
					1.19◆
Number of Voice Breaks	ASD	26.89		17.34	
	NTD	19.50		2.59	
	Mann-Whitney U				0.67
	Cohen’s d				0.64

[Voice break-related measurements of the elicited speech tasks “Counting” and “Happy Birthday”]

*denotes statistically significant task (p<0.050)

◆ denotes large effect size (d >0.80)

Table 34. Voice Break-Related Measurements (Spontaneous Speech Tasks)

Task	Group	Mean Value	Mean Individual variability within task (SD)	Mean Group variability within task (SD)	Significance
Story 1					
Degree of Voice Breaks (%)	ASD	74.32		9.49	
	NTD	75.01		9.48	
	Mann-Whitney U				0.79
					0.08
Number of Voice Breaks	ASD	19.00		8.37	
	NTD	18.00		5.51	
	Mann-Whitney U				0.97
	Cohen's d				0.15
Story 2					
Degree of Voice Breaks (%)	ASD	67.89		12.16	
	NTD	72.10		9.88	
	Mann-Whitney U				0.73
					0.40
Number of Voice Breaks	ASD	19.12		5.06	
	NTD	21.33		6.38	
	Mann-Whitney U				0.52
	Cohen's d				0.40
Topic of Interest					
Degree of Voice Breaks (%)	ASD	62.59		16.07	
	NTD	65.45		13.78	
	Mann-Whitney U				0.65
	Cohen's d				0.20
Number of Voice Breaks	ASD	32.34		20.74	
	NTD	26.00		10.43	
	Mann-Whitney U				0.59

	Cohen's d				0.43

[Voice break-related measurements of the spontaneous speech tasks Story 1, Story 2, and Topic of Interest]

*denotes statistically significant task (p<0.050)

◆ denotes large effect size (d >0.80)

Table 35. Voice Irregularity-Related Measurements ([a] and [i])

Task	**Group**	**Mean Value**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
[a]					
Mean Degree of Voiceless (%)	ASD	4.51	2.83	6.82	
	NTD	0.00	0.00	0.00	
	Mann-Whitney U				0.07
	Cohen’s d				0.97◆
Mean Number of Unvoiced Segments	ASD	0.75	0.86	1.10	
	NTD	0.00	0.00	0.00	
	Mann-Whitney U				0.15
	Cohen’s d				1.00◆
Mean Number of Segments Computed	ASD	48.05	5.46	21.73	
	NTD	64.97	0.82	3.42	
	Mann-Whitney U				0.46
	Cohen’s d				1.13◆
Mean Total Pitch Periods Detected	ASD	411.60	55.25	231.76	
	NTD	494.42	20.61	110.68	
	Mann-Whitney U				0.55
	Cohen’s d				0.47
[i]					
Mean Degree of Voiceless (%)	ASD	3.21	1.44	6.46	
	NTD	0.94	1.25	1.85	
	Mann-Whitney U				0.68
	Cohen’s d				0.49
Mean Number of Unvoiced Segments	ASD	0.67	0.31	1.05	
	NTD	0.50	0.62	1.15	
	Mann-Whitney				0.78

	U				
	Cohen’s d				0.16
Mean Number of Segments Computed	ASD	43.93	6.80	24.43	
	NTD	61.53	3.84	7.47	
	Mann-Whitney U				0.20
	Cohen’s d				1.01◆
Mean Total Pitch Periods Detected	ASD	365.93	75.40	201.27	
	NTD	504.03	52.14	104.56	
	Mann-Whitney U				0.22
	Cohen’s d				0.89◆

[Voice irregularity-related measurements of the vowels [a] and [i]]
*denotes statistically significant task ($p<0.050$)
◆ denotes large effect size ($d >0.80$)

Table 36. Voice Irregularity-Related Measurements (Elicited Speech Tasks)

Task	**Group**	**Mean Value**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
Counting					
Degree of Voiceless (%)	ASD	49.71		15.96	
	NTD	53.52		11.68	
	Mann-Whitney U				0.71
	Cohen's d				0.29
Number of Unvoiced Segments	ASD	85.29		37.31	
	NTD	93.00		65.01	
	Mann-Whitney U				0.84
	Cohen's d				0.15
Number of Segments Computed	ASD	167.86		36.43	
	NTD	162.25		78.70	
	Mann-Whitney U				0.43
	Cohen's d				0.23
Total Pitch Periods Detected	ASD	578.14		202.74	
	NTD	448.50		245.03	
	Mann-Whitney U				0.26
	Cohen's d				0.60
Happy Birthday					
Degree of Voiceless (%)	ASD	51.20		12.36	
	NTD	41.55		7.44	
	Mann-Whitney U				0.11
	Cohen's d				1.01◆
Number of Unvoiced Segments	ASD	230.43		85.62	
	NTD	130.20		61.29	
	Mann-Whitney				0.01*

	U				
	Cohen's d				1.43◆
Number of Segments Computed	ASD	442.43		94.25	
	NTD	311.10		117.14	
	Mann-Whitney U				0.04*
	Cohen's d				1.29◆
Total Pitch Periods Detected	ASD	1638.29		669.99	
	NTD	1328.50		729.82	
	Mann-Whitney U				0.36
	Cohen's d				0.46

[Voice irregularity-related measurements of the elicited speech tasks "Counting" and "Happy Birthday"]
*denotes statistically significant task ($p<0.050$)
◆ denotes large effect size ($d >0.80$)

Table 37. Voice Irregularity-Related Measurements (Spontaneous Speech Tasks)

Task	**Group**	**Mean Value**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
Story 1					
Degree of Voiceless (%)	ASD	73.26		8.54	
	NTD	73.96		4.09	
	Mann-Whitney U				0.79
	Cohen's d				0.11
Number of Unvoiced Segments	ASD	365.88		43.10	
	NTD	370.50		19.82	
	Mann-Whitney U				0.68
	Cohen's d				0.15
Number of Segments Computed	ASD	499.38		1.41	
	NTD	501.00		3.49	
	Mann-Whitney U				0.27
	Cohen's d				0.63
Total Pitch Periods Detected	ASD	861.75		396.19	
	NTD	699.58		230.99	
	Mann-Whitney U				0.27
	Cohen's d				0.53
Story 2					
Degree of Voiceless (%)	ASD	69.30		11.39	
	NTD	69.64		7.13	
	Mann-Whitney U				0.68
	Cohen's d				0.04
Number of Unvoiced Segments	ASD	346.00		57.12	
	NTD	348.17		34.88	
	Mann-Whitney				0.68

	U				
	Cohen’s d				0.05
Number of Segments Computed	ASD	499.25		2.19	
	NTD	500.08		2.87	
	Mann-Whitney U				0.38
	Cohen’s d				0.34
Total Pitch Periods Detected	ASD	1066.62		306.50	
	NTD	851.17		274.63	
	Mann-Whitney U				0.14
	Cohen’s d				0.78
Topic of Interest					
Degree of Voiceless (%)	ASD	58.85		13.51	
	NTD	61.42		9.34	
	Mann-Whitney U				0.65
	Cohen’s d				0.23
Number of Unvoiced Segments	ASD	279.57		98.48	
	NTD	298.83		43.42	
	Mann-Whitney U				0.84
	Cohen’s d				0.27
Number of Segments Computed	ASD	461.86		102.69	
	NTD	488.25		31.22	
	Mann-Whitney U				0.38
	Cohen’s d				0.37
Total Pitch Periods Detected	ASD	1405.57		586.73	
	NTD	1056.00		408.57	
	Mann-Whitney U				1.00
	Cohen’s d				0.73

[Voice irregularity-related measurements of the spontaneous speech tasks Story 1, Story 2 and Topic of Interest]

*denotes statistically significant task ($p<0.050$)

◆ denotes large effect size ($d > 0.80$)

Table 38. Sub-Harmonic-Related Measurements ([a] and [i])

Task	**Group**	**Mean Value**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
[a]					
Mean Degree of Sub-Harmonics (%)	ASD	0.80	1.21	2.03	
	NTD	1.44	1.59	3.93	
	Mann-Whitney U				1.00
	Cohen's d				0.21
Mean Number of Sub-Harmonics	ASD	0.66	0.66	0.98	
	NTD	0.86	0.93	2.30	
	Mann-Whitney U				0.94
	Cohen's d				0.12
[i]					
Mean Degree of Sub-Harmonics (%)	ASD	1.94	0.40	5.80	
	NTD	0.60	1.04	1.09	
	Mann-Whitney U				0.43
	Cohen's d				0.33
Mean Number of Sub-Harmonics	ASD	0.96	0.22	2.89	
	NTD	0.25	0.43	0.53	
	Mann-Whitney U				0.68
	Cohen's d				0.62

[Sub-harmonic-related measurements of the vowels [a] and [i]]
*denotes statistically significant task ($p<0.050$)
◆ denotes large effect size ($d > 0.80$)

Table 39. Sub-Harmonic-Related Measurements (Elicited Speech Tasks)

Task	**Group**	**Mean Value**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
Counting					
Degree of Sub-Harmonics (%)	ASD	1.58		2.01	
	NTD	2.68		3.50	
	Mann-Whitney U				0.77
	Cohen's d				0.39
Number of Sub-Harmonics	ASD	1.00		1.15	
	NTD	1.50		1.93	
	Mann-Whitney U				0.84
	Cohen's d				0.32
Happy Birthday					
Degree of Sub-Harmonics (%)	ASD	2.99		2.43	
	NTD	1.47		0.99	
	Mann-Whitney U				0.13
	Cohen's d				0.88◆
Number of Sub-Harmonics	ASD	6.86		7.78	
	NTD	2.90		2.73	
	Mann-Whitney U				0.16
	Cohen's d				0.73

[Sub-Harmonic-related measurements of the elicited speech tasks "Counting" and "Happy Birthday"]
*denotes statistically significant task (p<0.050)
◆ denotes large effect size (d >0.80)

Table 40. Sub-Harmonic-Related Measurements (Spontaneous Speech Tasks)

Task	**Group**	**Mean Value**	**Mean Individual variability within task (SD)**	**Mean Group variability within task (SD)**	**Significance**
Story 1					
Degree of Sub-Harmonics (%)	ASD	1.07		1.35	
	NTD	2.40		1.81	
	Mann-Whitney U				0.12
	Cohen's d				0.87◆
Number of Sub-Harmonics	ASD	1.38		1.51	
	NTD	3.17		2.44	
	Mann-Whitney U				0.10
	Cohen's d				0.91◆
Story 2					
Degree of Sub-Harmonics (%)	ASD	1.72		1.35	
	NTD	3.65		3.92	
	Mann-Whitney U				0.34
	Cohen's d				0.68
Number of Sub-Harmonics	ASD	2.50		1.77	
	NTD	5.92		7.61	
	Mann-Whitney U				0.43
	Cohen's d				0.63
Topic of Interest					
Degree of Sub-Harmonics (%)	ASD	1.63		0.70	
	NTD	2.86		2.43	
	Mann-Whitney U				0.30
	Cohen's d				0.68
Number of Sub-Harmonics	ASD	2.86		1.07	
	NTD	5.25		4.63	
	Mann-				0.38

	Whitney U				
	Cohen's d				0.70

[Sub-Harmonic-related measurements of the spontaneous speech tasks Story 1, Story 2, and Topic of Interest]

*denotes statistically significant task (p<0.050)

◆ denotes large effect size (d >0.80)

Table 41. Novice Group's Perceptual Ratings of Counting 1-10

Parameter	Group	Mean Value	Mean Individual Variability within task (SD)	Mean Group Variability within task (SD)	Significance
Overall Severity	ASD	19.63	20.32	8.46	
	NTD	10.65	13.79	6.32	
	Cronbach's Alpha				0.80 ✢
	Mann-Whitney U				0.24
Roughness	ASD	4.34	11.62	2.90	
	NTD	7.42	11.63	7.50	
	Cronbach's Alpha				0.79 ✢
	Mann-Whitney U				0.09
Breathiness	ASD	7.74	12.89	4.29	
	NTD	6.26	12.56	4.41	
	Cronbach's Alpha				0.60
	Mann-Whitney U				0.61
Strain	ASD	3.83	9.93	2.49	
	NTD	4.79	10.47	4.30	
	Cronbach's Alpha				0.58
	Mann-Whitney U				0.40
Pitch	ASD	12.31	17.06	6.70	
	NTD	4.00	8.00	7.83	
	Cronbach's Alpha				0.69
	Mann-Whitney U				0.07
Loudness	ASD	7.73	10.28	11.87	
	NTD	4.48	8.47	5.91	
	Cronbach's Alpha				0.58
	Mann-Whitney U				0.87

[Perceptual ratings, reliability, and group differences from the novice group using the CAPE-V on the task Counting 1-10]

✢ denotes consistent and reliable task ($\alpha > 0.70$)

* denotes statistically significant task ($p < 0.050$)

◆ denotes large effect size ($d > 0.80$)

Table 42. Novice Group’s Perceptual Ratings of Happy Birthday

Parameter	**Group**	**Mean Value**	**Mean Individual Variability within task (SD)**	**Mean Group Variability within task (SD)**	**Significance**
Overall Severity	ASD	17.67	16.71	6.81	
	NTD	12.53	15.13	5.64	
	Cronbach’s Alpha				0.73 ✢
	Mann-Whitney U				0.76
Roughness	ASD	6.71	14.89	2.86	
	NTD	6.25	11.24	3.91	
	Cronbach’s Alpha				0.33
	Mann-Whitney U				0.49
Breathiness	ASD	9.76	14.72	5.26	
	NTD	9.67	13.49	7.64	
	Cronbach’s Alpha				0.79 ✢
	Mann-Whitney U				0.49
Strain	ASD	6.33	13.31	4.04	
	NTD	3.97	10.22	2.59	
	Cronbach’s Alpha				0.47
	Mann-Whitney U				0.87
Pitch	ASD	12.62	16.10	7.61	
	NTD	5.28	7.62	4.88	
	Cronbach’s Alpha				0.75 ✢
	Mann-Whitney U				0.52
Loudness	ASD	10.01	13.38	5.75	
	NTD	5.06	6.78	6.66	
	Cronbach’s Alpha				0.78 ✢
	Mann-Whitney U				0.55

[Perceptual ratings, reliability, and group differences from the novice group using the CAPE-V on the task Happy Birthday]

✢ denotes consistent and reliable task ($\alpha > 0.70$)

* denotes statistically significant task ($p < 0.050$)

◆ denotes large effect size ($d > 0.80$)

Table 43. Novice Group’s Perceptual Ratings of Story 1

Parameter	**Group**	**Mean Value**	**Mean Individual Variability within task (SD)**	**Mean Group Variability within task (SD)**	**Significance**
Overall Severity	ASD	29.26	23.91	11.39	
	NTD	17.98	17.48	11.44	
	Cronbach’s Alpha				0.91 ✢
	Mann-Whitney U				0.79
Roughness	ASD	7.27	17.32	3.07	
	NTD	10.45	12.30	11.72	
	Cronbach’s Alpha				0.92✢
	Mann-Whitney U				0.37
Breathiness	ASD	11.37	17.99	5.72	
	NTD	9.20	13.49	7.39	
	Cronbach’s Alpha				0.74 ✢
	Mann-Whitney U				0.68
Strain	ASD	7.73	16.50	4.96	
	NTD	7.12	11.73	8.73	
	Cronbach’s Alpha				0.84 ✢
	Mann-Whitney U				0.65
Pitch	ASD	19.72	22.33	9.06	
	NTD	8.20	11.96	4.13	
	Cronbach’s Alpha				0.74 ✢
	Mann-Whitney U				0.30
Loudness	ASD	10.26	13.58	9.52	
	NTD	9.52	12.68	9.38	
	Cronbach’s Alpha				0.80 ✢
	Mann-Whitney U				0.37

[Perceptual ratings, reliability, and group differences from the novice group using the CAPE-V on the task Story 1]

✢ denotes consistent and reliable task ($\alpha >0.70$)

*denotes statistically significant task ($p< 0.050$)

◆ denotes large effect size ($d >0.80$)

Table 44. Novice Group’s Perceptual Ratings of Story 2

Parameter	**Group**	**Mean Value**	**Mean Individual Variability within task (SD)**	**Mean Group Variability within task (SD)**	**Significance**
Overall Severity	ASD	27.22	22.28	9.92	
	NTD	12.92	14.20	8.82	
	Cronbach’s Alpha				0.89 ✣
	Mann-Whitney U				0.43
Roughness	ASD	7.60	16.14	4.77	
	NTD	6.50	10.25	8.67	
	Cronbach’s Alpha				0.86 ✣
	Mann-Whitney U				0.79
Breathiness	ASD	9.42	14.21	4.59	
	NTD	8.41	11.97	7.41	
	Cronbach’s Alpha				0.79 ✣
	Mann-Whitney U				0.46
Strain	ASD	7.60	15.41	5.18	
	NTD	4.03	9.41	4.11	
	Cronbach’s Alpha				0.65
	Mann-Whitney U				0.98
Pitch	ASD	17.18	17.41	9.14	
	NTD	5.48	9.04	3.64	
	Cronbach’s Alpha				0.82 ✣
	Mann-Whitney U				0.35
Loudness	ASD	9.33	11.66	11.70	
	NTD	7.04	11.52	7.02	
	Cronbach’s Alpha				0.83 ✣
	Mann-Whitney U				0.26

[Perceptual ratings, reliability, and group differences from the novice group using the CAPE-V on the task Story 2]

✣ denotes consistent and reliable task ($\alpha > 0.70$)

* denotes statistically significant task ($p < 0.050$)

◆ denotes large effect size ($d > 0.80$)

Table 45. Novice Group’s Perceptual Ratings of Topic of Interest

Parameter	**Group**	**Mean Value**	**Mean Individual Variability within task (SD)**	**Mean Group Variability within task (SD)**	**Significance**
Overall Severity	ASD	27.99	22.66	14.27	
	NTD	13.32	15.08	7.44	
	Cronbach’s Alpha				0.91 ✢
	Mann-Whitney U				0.91
Roughness	ASD	4.66	12.47	2.17	
	NTD	6.26	10.87	4.37	
	Cronbach’s Alpha				0.35
	Mann-Whitney U				0.04*
Breathiness	ASD	6.66	13.11	3.62	
	NTD	7.82	11.97	6.25	
	Cronbach’s Alpha				0.67
	Mann-Whitney U				0.07
Strain	ASD	7.32	14.13	6.72	
	NTD	3.98	10.10	2.76	
	Cronbach’s Alpha				0.76 ✢
	Mann-Whitney U				0.52
Pitch	ASD	19.49	19.82	12.49	
	NTD	7.09	11.75	5.37	
	Cronbach’s Alpha				0.85 ✢
	Mann-Whitney U				0.87
Loudness	ASD	10.01	11.78	8.49	
	NTD	5.96	9.10	6.71	
	Cronbach’s Alpha				0.86 ✢
	Mann-Whitney U				0.52

[Perceptual ratings, reliability, and group differences from the novice group using the CAPE-V on the task Topic of Interest]

✢ denotes consistent and reliable task ($\alpha > 0.70$)

* denotes statistically significant task ($p < 0.050$)

◆ denotes large effect size ($d > 0.80$)

Table 46. Expert Group's Perceptual Ratings of Counting 1-10

Parameter	**Group**	**Mean Value**	**Mean Individual Variability within task (SD)**	**Mean Group Variability within task (SD)**	**Significance**
Overall Severity	ASD	12.15	13.29	6.24	
	NTD	12.73	10.26	7.14	
	Cronbach's Alpha				0.47
	Mann-Whitney U				0.77
	Cohen's d				0.09
Roughness	ASD	4.74	5.66	4.27	
	NTD	9.82	9.64	8.49	
	Cronbach's Alpha				0.78 ✢
	Mann-Whitney U				0.16
	Cohen's d				0.76
Breathiness	ASD	2.66	4.12	2.51	
	NTD	7.88	9.34	6.70	
	Cronbach's Alpha				0.61
	Mann-Whitney U				0.11
	Cohen's d				1.03◆
Strain	ASD	3.53	5.56	3.01	
	NTD	3.52	5.44	4.13	
	Cronbach's Alpha				0.47
	Mann-Whitney U				0.45
	Cohen's d				0.00
Pitch	ASD	8.88	12.48	6.96	
	NTD	4.97	8.55	5.56	
	Cronbach's Alpha				0.55
	Mann-Whitney U				0.06
	Cohen's d				0.65
Loudness	ASD	8.47	13.02	7.78	
	NTD	5.10	9.01	4.49	
	Cronbach's Alpha				0.37
	Mann-Whitney U				0.73

	Cohen’s d				0.57

[Perceptual ratings, reliability, and group differences from the expert group using the CAPE-V on the task Counting 1-10]

✢ denotes consistent and reliable task ($\alpha > 0.70$)

* denotes statistically significant task ($p < 0.050$)

◆ denotes large effect size ($d > 0.80$)

Table 47. Expert Group's Perceptual Ratings of Happy Birthday

Parameter	**Group**	**Mean Value**	**Mean Individual Variability within task (SD)**	**Mean Group Variability within task (SD)**	**Significance**
Overall Severity	ASD	12.67	10.85	5.79	
	NTD	11.86	9.17	5.77	
	Cronbach's Alpha				0.46
	Mann-Whitney U				0.31
	Cohen's d				0.15
Roughness	ASD	4.97	5.81	3.66	
	NTD	8.23	7.36	7.40	
	Cronbach's Alpha				0.78 ✢
	Mann-Whitney U				0.86
	Cohen's d				0.57
Breathiness	ASD	4.55	6.66	4.58	
	NTD	9.92	8.44	8.97	
	Cronbach's Alpha				0.74✢
	Mann-Whitney U				0.46
	Cohen's d				0.77
Strain	ASD	3.58	5.91	2.80	
	NTD	2.40	3.93	2.61	
	Cronbach's Alpha				0.25
	Mann-Whitney U				0.24
	Cohen's d				0.46
Pitch	ASD	10.09	13.44	10.12	
	NTD	5.21	6.88	7.74	
	Cronbach's Alpha				0.67
	Mann-Whitney U				0.16
	Cohen's d				0.57
Loudness	ASD	5.42	11.04	4.69	
	NTD	4.95	8.10	6.65	
	Cronbach's Alpha				0.40
	Mann-				0.27

	Whitney U				
	Cohen's d				0.08

[Perceptual ratings, reliability, and group differences from the expert group using the CAPE-V on the task Happy Birthday]

✢ denotes consistent and reliable task ($\alpha > 0.70$)

*denotes statistically significant task ($p < 0.050$)

◆ denotes large effect size ($d > 0.80$)

Table 48. Expert Group's Perceptual Ratings of Story 1

Parameter	Group	Mean Value	Mean Individual Variability within task (SD)	Mean Group Variability within task (SD)	Significance
Overall Severity	ASD	18.17	13.39	9.00	
	NTD	17.93	11.73	11.88	
	Cronbach's Alpha				0.77[†]
	Mann-Whitney U				0.92
	Cohen's d				0.02
Roughness	ASD	6.80	8.09	6.56	
	NTD	12.62	10.36	12.39	
	Cronbach's Alpha				0.83[†]
	Mann-Whitney U				0.82
	Cohen's d				0.59
Breathiness	ASD	4.96	6.21	5.67	
	NTD	7.51	8.58	8.53	
	Cronbach's Alpha				0.68
	Mann-Whitney U				0.76
	Cohen's d				0.36
Strain	ASD	8.48	9.11	8.41	
	NTD	9.04	10.01	9.63	
	Cronbach's Alpha				0.73[†]
	Mann-Whitney U				0.71
	Cohen's d				0.06
Pitch	ASD	8.45	11.32	8.87	
	NTD	5.69	8.74	5.06	
	Cronbach's Alpha				0.58
	Mann-Whitney U				0.87
	Cohen's d				0.41
Loudness	ASD	10.62	15.73	8.37	
	NTD	8.75	11.57	6.44	
	Cronbach's Alpha				0.52
	Mann-Whitney U				1.00
	Cohen's d				0.27

[Perceptual ratings, reliability, and group differences from the expert group using the CAPE-V on the task Story 1]

ᐩ denotes consistent and reliable task ($\alpha > 0.70$)

* denotes statistically significant task ($p < 0.050$)

◆ denotes large effect size ($d > 0.80$)

Table 49. Expert Group’s Perceptual Ratings of Story 2

Parameter	**Group**	**Mean Value**	**Mean Individual Variability within task (SD)**	**Mean Group Variability within task (SD)**	**Significance**
Overall Severity	ASD	17.08	12.96	6.74	
	NTD	14.62	9.72	10.73	
	Cronbach’s Alpha				0.75†
	Mann-Whitney U				0.05
	Cohen’s d				0.28
Roughness	ASD	7.55	8.31	6.34	
	NTD	9.41	7.73	11.80	
	Cronbach’s Alpha				0.87†
	Mann-Whitney U				0.71
	Cohen’s d				0.20
Breathiness	ASD	3.15	5.42	2.13	
	NTD	7.10	9.03	7.79	
	Cronbach’s Alpha				0.63
	Mann-Whitney U				0.57
	Cohen’s d				0.68
Strain	ASD	6.74	7.62	7.64	
	NTD	4.81	7.58	5.14	
	Cronbach’s Alpha				0.64
	Mann-Whitney U				0.57
	Cohen’s d				0.32
Pitch	ASD	6.15	9.10	7.03	
	NTD	6.00	10.05	5.20	
	Cronbach’s Alpha				0.42
	Mann-Whitney U				0.71
	Cohen’s d				0.03
Loudness	ASD	7.56	12.39	7.28	
	NTD	6.96	9.56	6.73	
	Cronbach’s Alpha				0.36
	Mann-Whitney U				0.30
	Cohen’s d				0.09

[Perceptual ratings, reliability, and group differences from the expert group using the CAPE-V on the task Story 2]
✢ denotes consistent and reliable task ($\alpha > 0.70$)
* denotes statistically significant task ($p < 0.050$)
◆ denotes large effect size ($d > 0.80$)

Table 50. Expert Group’s Perceptual Ratings of Topic of Interest

Parameter	**Group**	**Mean Value**	**Mean Individual Variability within task (SD)**	**Mean Group Variability within task (SD)**	**Significance**
Overall Severity	ASD	15.54	13.39	10.00	
	NTD	13.95	12.24	6.92	
	Cronbach’s Alpha				0.57
	Mann-Whitney U				0.49
	Cohen’s d				0.20
Roughness	ASD	3.82	5.61	3.84	
	NTD	9.36	9.92	7.00	
	Cronbach’s Alpha				0.62
	Mann-Whitney U				0.07
	Cohen’s d				0.97◆
Breathiness	ASD	2.15	3.68	2.30	
	NTD	7.13	8.98	7.56	
	Cronbach’s Alpha				0.67
	Mann-Whitney U				0.15
	Cohen’s d				0.85◆
Strain	ASD	8.58	8.20	9.64	
	NTD	5.43	6.51	4.65	
	Cronbach’s Alpha				0.77†
	Mann-Whitney U				0.36
	Cohen’s d				0.47
Pitch	ASD	7.13	10.88	7.37	
	NTD	4.33	6.64	4.64	
	Cronbach’s Alpha				0.41
	Mann-Whitney U				0.36
	Cohen’s d				0.50
Loudness	ASD	7.41	8.94	7.19	
	NTD	4.70	7.53	5.15	
	Cronbach’s Alpha				0.44
	Mann-				0.29

	Whitney U				
	Cohen’s d				0.47

[Perceptual ratings, reliability, and group differences from the expert group using the CAPE-V on the task Topic of Interest]

✢ denotes consistent and reliable task ($\alpha > 0.70$)

* denotes statistically significant task ($p < 0.050$)

◆ denotes large effect size ($d > 0.80$)

Table 51. Correlations from the Expert Group Roughness Rating with the Voice Analysis of Counting 1-10

	Parameter	Group	Mean Value	Pearson r	Significance
CAPE-V Measurement	**Roughness**	ASD	4.73	n/a	n/a
		NTD	9.82	n/a	n/a
Fundamental Frequency Measurements	**Average Fundamental Frequency**	ASD	270.13		
		NTD	234.75		
		Pearson		-0.16	0.52
	Mean Fundamental Frequency	ASD	262.63		
		NTD	230.30		
		Pearson		-0.20	0.41
	Average Pitch Period	ASD	3.93		
		NTD	4.51		
		Pearson		0.29	0.23
	Highest Fundamental Frequency	ASD	379.96		
		NTD	314.44		
		Pearson		-0.02	0.93
	Lowest Fundamental Frequency	ASD	164.19		
		NTD	162.72		
		Pearson		-0.15	0.54
	Standard Deviation of f0	ASD	47.33		
		NTD	29.96		
		Pearson		0.17	0.48
	Phonatory f0 range in Semi-Tones	ASD	15.86		
		NTD	13.12		
		Pearson		0.15	0.53
Short- and Long-Term Frequency Perturbation Measurements	**Absolute Jitter**	ASD	103.09		
		NTD	156.65		
		Pearson		0.45	0.05
	Jitter Percent	ASD	2.68		
		NTD	3.43		
		Pearson		0.42	0.07
	Relative Average Perturbation	ASD	1.54		
		NTD	2.03		
		Pearson		0.35	0.15
	Pitch Perturbation Quotient	ASD	1.71		
		NTD	2.22		
		Pearson		0.29	0.23
	Smoothed Pitch Perturbation Quotient	ASD	6.77		
		NTD	4.98		
		Pearson		0.51	0.03*
	Fundamental Frequency Variation	ASD	16.13		
		NTD	13.79		
		Pearson		0.37	0.12

Short- and Long-Term Amplitude Perturbation Measurements	**Shimmer in dB**	ASD	0.72		
		NTD	0.87	0.51	0.03*
	Shimmer in Percent	ASD	6.75		
		NTD	7.87		
		Pearson		0.58	0.01*
	Amplitude Perturbation Quotient	ASD	7.62		
		NTD	8.14		
		Pearson		0.67	0.00*
	Smoothed Amplitude Perturbation Quotient	ASD	22.58		
		NTD	25.42		
		Pearson		0.42	0.08
	Peak to Peak Amplitude Variation	ASD	48.01		
		NTD	42.55		
		Pearson		-0.10	0.69
Noise-Related Measurements	**Noise to Harmonics Ratio**	ASD	0.25		
		NTD	0.24		
		Pearson		0.24	0.33
	Voice Turbulence Index	ASD	0.09		
		NTD	0.14		
		Pearson		-0.15	0.53
	Soft Phonation Index	ASD	21.82		
		NTD	21.68		
		Pearson		-0.16	0.52
Tremor-Related Measurements	**Amplitude Frequency**	ASD	3.56		
		NTD	2.99		
		Pearson		-0.01	0.98
	f0 Tremor Intensity Index	ASD	1.72		
		NTD	2.87		
		Pearson		0.78	0.00*
	Amplitude Tremor Intensity Index	ASD	6.48		
		NTD	10.76		
		Pearson		0.50	0.04*
Voice Break-Related Measurements	**Degree of Voice Breaks**	ASD	54.12		
		NTD	57.20		
		Pearson		-0.10	0.67
	Number of Voice Breaks	ASD	9.71		
		NTD	9.25		
		Pearson		-0.10	0.67
Sub-harmonic-Related Measurements	**Degree of Sub-Harmonics**	ASD	1.58		
		NTD	2.68		
		Pearson		0.72	0.00*
	Number of Sub-harmonic Segments	ASD	1.00		
		NTD	1.50		
		Pearson		0.74	0.00*
Voice Irregularity-Related	**Degree of Voiceless**	ASD	49.71		
		NTD	53.52		
		Pearson		-0.11	0.66

Measurements	**Number of Unvoiced Segments**	ASD	85.29		
		NTD	93.00		
		Pearson		-0.27	0.27
	Number of Segments Computed	ASD	167.86		
		NTD	162.25		
		Pearson		-0.33	0.17
	Total Number Detected Pitch Periods	ASD	578.14		
		NTD	448.50		
		Pearson		-0.30	0.22

[Results of the correlation between the Roughness parameter for the task Counting 1-10, as rated by the Expert Group using the CAPE-V and the results of the voice analysis from the MDVP]
*denotes statistically significant correlation, $p<0.050$

Table 52. Correlations from the Expert Group Breathiness Rating and the Voice Analysis of Happy Birthday

	Parameter	**Group**	**Mean Value**	**Pearson r**	**Significance**
CAPE-V Measurement	**Breathiness**	ASD	4.55	n/a	n/a
		NTD	9.92	n/a	n/a
Fundamental Frequency Measurements	**Average Fundamental Frequency**	ASD	328.54		
		NTD	255.50		
		Pearson		-0.37	0.14
	Mean Fundamental Frequency	ASD	320.18		
		NTD	259.21		
		Pearson		0.33	0.19
	Average Pitch Period	ASD	3.25		
		NTD	4.14		
		Pearson		0.54	0.26*
	Highest Fundamental Frequency	ASD	484.68		
		NTD	356.22		
		Pearson		-0.48	0.50
	Lowest Fundamental Frequency	ASD	177.50		
		NTD	158.86		
		Pearson		-0.51	0.04*
	Standard Deviation of f0	ASD	54.20		
		NTD	42.22		
		Pearson		0.16	0.54
	Phonatory f0 range in Semi-Tones	ASD	19.00		
		NTD	15.50		
		Pearson		0.26	0.31
Short- and Long-Term Frequency Perturbation Measurements	**Absolute Jitter**	ASD	72.53		
		NTD	111.01		
		Pearson		0.461	0.062
	Jitter Percent	ASD	2.28		
		NTD	2.70		
		Pearson		0.10	0.70
	Relative Average Perturbation	ASD	1.36		
		NTD	1.59		
		Pearson		0.09	0.74
	Pitch Perturbation Quotient	ASD	1.40		
		NTD	1.68		
		Pearson		0.13	0.63
	Smoothed Pitch Perturbation Quotient	ASD	3.57		
		NTD	4.66		
		Pearson		0.51	0.04*
	Fundamental Frequency	ASD	16.55		
		NTD	16.98		

	Variation	Pearson		0.53	0.03*
Short- and Long-Term Amplitude Perturbation Measurements	**Shimmer in dB**	ASD	0.53		
		NTD	0.68		
		Pearson		0.47	0.06
	Shimmer in Percent	ASD	5.06		
		NTD	5.83		
		Pearson		0.47	0.07
	Amplitude Perturbation Quotient	ASD	4.75		
		NTD	6.12		
		Pearson		0.36	0.16
	Smoothed Amplitude Perturbation Quotient	ASD	14.14		
		NTD	16.97		
		Pearson		0.07	0.80
	Peak to Peak Amplitude Variation	ASD	36.33		
		NTD	42.23		
		Pearson		0.10	0.71
Noise-Related Measurements	**Noise to Harmonics Ratio**	ASD	0.19		
		NTD	0.22		
		Pearson		0.28	0.28
	Voice Turbulence Index	ASD	0.09		
		NTD	0.12		
		Pearson		-0.06	0.82
	Soft Phonation Index	ASD	17.42		
		NTD	21.01		
		Pearson		-0.16	0.55
Tremor-Related Measurements	**Amplitude Frequency**	ASD	4.30		
		NTD	4.19		
		Pearson		-0.13	0.61
	f0 Tremor Intensity Index	ASD	1.83		
		NTD	2.37		
		Pearson		0.26	0.42
	Amplitude Tremor Intensity Index	ASD	6.36		
		NTD	7.34		
		Pearson		0.18	0.48
Voice Break-Related Measurements	**Degree of Voice Breaks**	ASD	57.62		
		NTD	43.29		
		Pearson		-0.26	0.31
	Number of Voice Breaks	ASD	26.89		
		NTD	19.50		
		Pearson		0.18	0.60
Sub-Harmonic-Related Measurements	**Degree of Sub-Harmonics**	ASD	2.99		
		NTD	1.47		
		Pearson		-0.02	0.94
	Number of Sub-harmonic Segments	ASD	6.86		
		NTD	2.90		
		Pearson		0.01	0.99

Voice Irregularity - Related Measurements	**Degree of Voiceless**	ASD	51.20		
		NTD	41.55		
		Pearson		-0.21	0.43
	Number of Unvoiced Segments	ASD	230.43		
		NTD	130.20		
		Pearson		-0.33	0.20
	Number of Segments Computed	ASD	442.43		
		NTD	311.10		
		Pearson		-0.35	0.17
	Total Number Detected Pitch Periods	ASD	1638.29		
		NTD	1328.50		
		Pearson		-0.23	0.38

[Results of the correlation between the Breathiness parameter for the task Happy Birthday, as rated by the Expert Group using the CAPE-V and the results of the voice analysis from the MDVP]
*denotes statistically significant correlation, p<0.050

Table 53. Correlations from the Expert Group Roughness Rating and the Voice Analysis of Happy Birthday

	Parameter	Group	Mean Value	Pearson r	Significance
CAPE-V Measurement	**Roughness**	ASD	4.55	n/a	n/a
		NTD	9.92	n/a	n/a
Fundamental Frequency Measurements	**Average Fundamental Frequency**	ASD	328.54		
		NTD	255.50		
		Pearson		0.04	0.87
	Mean Fundamental Frequency	ASD	320.18		
		NTD	259.21		
		Pearson		0.24	0.35
	Average Pitch Period	ASD	3.25		
		NTD	4.14		
		Pearson		-0.21	0.41
	Highest Fundamental Frequency	ASD	484.68		
		NTD	356.22		
		Pearson		-0.07	0.79
	Lowest Fundamental Frequency	ASD	177.50		
		NTD	158.86		
		Pearson		0.29	0.26
	Standard Deviation of f0	ASD	54.20		
		NTD	42.22		
		Pearson		-0.33	0.20
	Phonatory f0 range in Semi-Tones	ASD	19.00		
		NTD	15.50		
		Pearson		-0.36	0.15
Short- and Long-Term Frequency Perturbation Measurements	**Absolute Jitter**	ASD	72.53		
		NTD	111.01		
		Pearson		0.15	0.58
	Jitter Percent	ASD	2.28		
		NTD	2.70		
		Pearson		0.40	0.11
	Relative Average Perturbation	ASD	1.36		
		NTD	1.59		
		Pearson		0.38	0.13
	Pitch Perturbation Quotient	ASD	1.40		
		NTD	1.68		
		Pearson		0.41	0.10
	Smoothed Pitch Perturbation Quotient	ASD	3.57		
		NTD	4.66		
		Pearson		-0.21	0.42

	Fundamental Frequency Variation	ASD	16.55		
		NTD	16.98		
		Pearson		-0.364	0.15
Short- and Long-Term Amplitude Perturbation Measurements	**Shimmer in dB**	ASD	0.53		
		NTD	0.68		
		Pearson		-0.02	0.96
	Shimmer in Percent	ASD	5.06		
		NTD	5.83		
		Pearson		-0.24	0.38
	Amplitude Perturbation Quotient	ASD	4.75		
		NTD	6.12		
		Pearson		-0.00	0.99
	Smoothed Amplitude Perturbation Quotient	ASD	14.14		
		NTD	16.97		
		Pearson		-0.18	0.50
	Peak to Peak Amplitude Variation	ASD	36.33		
		NTD	42.23		
		Pearson		0.25	0.33
Noise-Related Measurements	**Noise to Harmonics Ratio**	ASD	0.19		
		NTD	0.22		
		Pearson		0.22	0.39
	Voice Turbulence Index	ASD	0.09		
		NTD	0.12		
		Pearson		0.20	0.45
	Soft Phonation Index	ASD	17.42		
		NTD	21.01		
		Pearson		0.09	0.74
Tremor-Related Measurements	**Amplitude Frequency**	ASD	4.30		
		NTD	4.19		
		Pearson		0.23	0.37
	f0 Tremor Intensity Index	ASD	1.83		
		NTD	2.37		
		Pearson		-0.08	0.80
	Amplitude Tremor Intensity Index	ASD	6.36		
		NTD	7.34		
		Pearson		-0.27	0.29
Voice Break-Related Measurements	**Degree of Voice Breaks**	ASD	57.62		
		NTD	43.29		
		Pearson		-0.17	0.53
	Number of Voice Breaks	ASD	26.89		
		NTD	19.50		
		Pearson		-0.08	0.80
Sub-Harmonic-Related Measurements	**Degree of Sub-Harmonics**	ASD	2.99		
		NTD	1.47		
		Pearson		-0.21	0.42
	Number of	ASD	6.86		

	Sub-harmonic Segments	NTD	2.90		
		Pearson		-0.13	0.61
Voice Irregularity - Related Measurements	**Degree of Voiceless**	ASD	51.20		
		NTD	41.55		
		Pearson		-0.10	0.70
	Number of Unvoiced Segments	ASD	230.43		
		NTD	130.20		
		Pearson		-0.15	0.57
	Number of Segments Computed	ASD	442.43		
		NTD	311.10		
		Pearson		-0.13	0.61
	Total Number Detected Pitch Periods	ASD	1638.29		
		NTD	1328.50		
		Pearson		0.10	0.70

[Results of the correlation between the Roughness parameter for the task Happy Birthday, as rated by the Expert Group using the CAPE-V and the results of the voice analysis from the MDVP]
*denotes statistically significant correlation, p<0.050

Table 54. Correlations from the Expert Group Overall Severity Rating and the Voice Analysis of Story 1

	Parameter	**Group**	**Mean Value**	**Pearson r**	**Significance**
CAPE-V Measurement	**Overall Severity**	ASD	18.17	n/a	n/a
		NTD	17.93	n/a	n/a
Fundamental Frequency Measurements	**Average Fundamental Frequency**	ASD	265.93		
		NTD	222.85		
		Pearson		0.00	0.99
	Mean Fundamental Frequency	ASD	259.81		
		NTD	222.13		
		Pearson		-0.06	0.81
	Average Pitch Period	ASD	3.91		
		NTD	4.59		
		Pearson		0.09	0.72
	Highest Fundamental Frequency	ASD	416.27		
		NTD	317.31		
		Pearson		-0.11	0.65
	Lowest Fundamental Frequency	ASD	157.17		
		NTD	143.75		
		Pearson		0.03	0.90
	Standard Deviation of f0	ASD	41.77		
		NTD	24.78		
		Pearson		0.35	0.13
	Phonatory f0 range in Semi-Tones	ASD	18.25		
		NTD	15.25		
		Pearson		-0.08	0.73
Short- and Long-Term Frequency Perturbation Measurements	**Absolute Jitter**	ASD	111.90		
		NTD	158.60		
		Pearson		0.55	0.01*
	Jitter Percent	ASD	3.47		
		NTD	3.40		
		Pearson		0.40	0.08
	Relative Average Perturbation	ASD	1.65		
		NTD	1.98		
		Pearson		0.55	0.01*
	Pitch Perturbation Quotient	ASD	1.92		
		NTD	4.36		
		Pearson		0.10	0.67
	Smoothed Pitch Perturbation Quotient	ASD	5.79		
		NTD	5.81		
		Pearson		0.69	0.00*
	Fundamental Frequency Variation	ASD	15.52		
		NTD	11.51		
		Pearson		0.47	0.04*
Short- and	**Shimmer in**	ASD	0.75		

Long-Term Amplitude Perturbation Measurements	**dB**	NTD	0.77		
		Pearson		0.37	0.11
	Shimmer in Percent	ASD	7.36		
		NTD	7.74		
		Pearson		0.49	0.03*
	Amplitude Perturbation Quotient	ASD	7.91		
		NTD	8.04		
		Pearson		0.40	0.08
	Smoothed Amplitude Perturbation Quotient	ASD	22.68		
		NTD	20.10		
		Pearson		0.23	0.32
	Peak to Peak Amplitude Variation	ASD	76.61		
		NTD	37.38		
		Pearson		-0.06	0.80
Noise-Related Measurements	**Noise to Harmonics Ratio**	ASD	0.28		
		NTD	0.27		
		Pearson		0.17	0.47
	Voice Turbulence Index	ASD	0.18		
		NTD	0.12		
		Pearson		-0.10	0.67
	Soft Phonation Index	ASD	19.39		
		NTD	21.88		
		Pearson		-0.30	0.19
Tremor-Related Measurements	**Amplitude Frequency**	ASD	4.37		
		NTD	1.77		
		Pearson		-0.10	0.68
	f0 Tremor Intensity Index	ASD	1.40		
		NTD	0.90		
		Pearson		0.07	0.79
	Amplitude Tremor Intensity Index	ASD	4.28		
		NTD	3.98		
		Pearson		0.04	0.85
Voice Break-Related Measurements	**Degree of Voice Breaks**	ASD	74.32		
		NTD	75.01		
		Pearson		0.35	0.13
	Number of Voice Breaks	ASD	19.00		
		NTD	18.00		
		Pearson		0.23	0.32
Sub-Harmonic-Related Measurements	**Degree of Sub-Harmonics**	ASD	1.07		
		NTD	2.40		
		Pearson		0.22	0.36
	Number of Sub-harmonic Segments	ASD	1.38		
		NTD	3.17		
		Pearson		0.11	0.65
Voice Irregularity-Related Measurements	**Degree of Voiceless**	ASD	73.26		
		NTD	73.96		
		Pearson		0.60	0.01*
	Number of	ASD	365.88		

	Unvoiced Segments	NTD	370.50		
		Pearson		0.56	0.010*
	Number of Segments Computed	ASD	499.38		
		NTD	501.00		
		Pearson		0.04	0.87
	Total Number Detected Pitch Periods	ASD	861.75		
		NTD	699.58		
		Pearson		-0.38	0.10

[Results of the correlation between the Overall Severity parameter for the task Story 1, as rated by the Expert Group using the CAPE-V and the results of the voice analysis from the MDVP]

Table 55. Correlations from the Expert Group Roughness Rating and the Voice Analysis of Story 1

	Parameter	Group	Mean Value	Pearson r	Significance
CAPE-V Measurement	**Roughness**	ASD	6.80	n/a	n/a
		NTD	12.62	n/a	n/a
Fundamental Frequency Measurements	**Average Fundamental Frequency**	ASD	265.93		
		NTD	222.85		
		Pearson		-0.37	0.11
	Mean Fundamental Frequency	ASD	259.81		
		NTD	222.13		
		Pearson		-0.44	0.06
	Average Pitch Period	ASD	3.91		
		NTD	4.59		
		Pearson		0.47	0.04*
	Highest Fundamental Frequency	ASD	416.27		
		NTD	317.31		
		Pearson		-0.29	0.22
	Lowest Fundamental Frequency	ASD	157.17		
		NTD	143.75		
		Pearson		-0.36	0.12
	Standard Deviation of f0	ASD	41.77		
		NTD	24.78		
		Pearson		0.39	0.09
	Phonatory f0 range in Semi-Tones	ASD	18.25		
		NTD	15.25		
		Pearson		0.15	0.52
Short- and Long-Term Frequency Perturbation Measurements	**Absolute Jitter**	ASD	111.90		
		NTD	158.60		
		Pearson		0.88	0.00*
	Jitter Percent	ASD	3.47		
		NTD	3.40		
		Pearson		0.54	0.02*
	Relative Average Perturbation	ASD	1.65		
		NTD	1.98		
		Pearson		0.81	0.00*
	Pitch Perturbation Quotient	ASD	1.92		
		NTD	4.36		
		Pearson		0.17	0.47
	Smoothed Pitch Perturbation Quotient	ASD	5.79		
		NTD	5.81	0.87	0.00*
		Pearson			
	Fundamental Frequency	ASD	15.52		
		NTD	11.51		

	Variation	Pearson		0.62	0.00*
Short- and Long-Term Amplitude Perturbation Measurements	**Shimmer in dB**	ASD	0.75		
		NTD	0.77		
		Pearson		0.32	0.17
	Shimmer in Percent	ASD	7.36		
		NTD	7.74		
		Pearson		0.16	0.02*
	Amplitude Perturbation Quotient	ASD	7.91		
		NTD	8.04		
		Pearson		0.30	0.19
	Smoothed Amplitude Perturbation Quotient	ASD	22.68		
		NTD	20.10		
		Pearson		-0.04	0.89
	Peak to Peak Amplitude Variation	ASD	76.61		
		NTD	37.38		
		Pearson		-0.15	0.54
Noise-Related Measurements	**Noise to Harmonics Ratio**	ASD	0.28		
		NTD	0.27		
		Pearson		0.08	0.73
	Voice Turbulence Index	ASD	0.18		
		NTD	0.12		
		Pearson		-0.07	0.76
	Soft Phonation Index	ASD	19.39		
		NTD	21.88		
		Pearson		-0.27	0.25
Tremor-Related Measurements	**Amplitude Frequency**	ASD	4.37		
		NTD	1.77		
		Pearson		0.01	0.96
	f0 Tremor Intensity Index	ASD	1.40		
		NTD	0.90		
		Pearson		-0.02	0.94
	Amplitude Tremor Intensity Index	ASD	4.28		
		NTD	3.98		
		Pearson		-0.29	0.21
Voice Break-Related Measurements	**Degree of Voice Breaks**	ASD	74.32		
		NTD	75.01		
		Pearson		0.39	0.09
	Number of Voice Breaks	ASD	19.00		
		NTD	18.00		
		Pearson		-0.27	0.25
Sub-Harmonic-Related Measurements	**Degree of Sub-Harmonics**	ASD	1.07		
		NTD	2.40		
		Pearson		0.55	0.01*
	Number of Sub-harmonic Segments	ASD	1.38		
		NTD	3.17		
		Pearson		0.47	0.04*
Voice Irregularity-	**Degree of Voiceless**	ASD	73.26		
		NTD	73.96		

Related Measurements		Pearson		0.27	0.25
	Number of Unvoiced Segments	ASD	365.88		
		NTD	370.50		
		Pearson		0.28	0.24
	Number of Segments Computed	ASD	499.38		
		NTD	501.00		
		Pearson		0.14	0.57
	Total Number Detected Pitch Periods	ASD	861.75		
		NTD	699.58		
		Pearson		-0.48	0.03*

[Results of the correlation between the Roughness parameter for the task Story 1, as rated by the Expert Group using the CAPE-V and the results of the voice analysis from the MDVP]
*denotes statistically significant correlation, $p<0.050$

Table 56. Correlations from the Expert Group Strain Rating and the Voice Analysis of Story 1

	Parameter	Group	Mean Value	Pearson r	Significance
CAPE-V Measurement	**Strain**	ASD	8.48	n/a	n/a
		NTD	9.04	n/a	n/a
Fundamental Frequency Measurements	**Average Fundamental Frequency**	ASD	265.93		
		NTD	222.85		
		Pearson		-0.14	0.56
	Mean Fundamental Frequency	ASD	259.81		
		NTD	222.13		
		Pearson		-0.22	0.36
	Average Pitch Period	ASD	3.91		
		NTD	4.59		
		Pearson		0.23	0.34
	Highest Fundamental Frequency	ASD	416.27		
		NTD	317.31		
		Pearson		-0.10	0.69
	Lowest Fundamental Frequency	ASD	157.17		
		NTD	143.75		
		Pearson		-0.16	0.50
	Standard Deviation of f0	ASD	41.77		
		NTD	24.78		
		Pearson		0.33	0.15
	Phonatory f0 range in Semi-Tones	ASD	18.25		
		NTD	15.25		
		Pearson		0.08	0.73
Short- and Long-Term Frequency Perturbation Measurements	**Absolute Jitter**	ASD	111.90		
		NTD	158.60		
		Pearson		0.42	0.07
	Jitter Percent	ASD	3.47		
		NTD	3.40		
		Pearson		0.10	0.67
	Relative Average Perturbation	ASD	1.65		
		NTD	1.98		
		Pearson		0.32	0.17
	Pitch Perturbation Quotient	ASD	1.92		
		NTD	4.36		
		Pearson		-0.09	0.72
	Smoothed Pitch Perturbation Quotient	ASD	5.79		
		NTD	5.81		
		Pearson		0.66	0.00*
	Fundamental Frequency Variation	ASD	15.52		
		NTD	11.51		
		Pearson		0.47	0.04*

Short- and Long-Term Amplitude Perturbation Measurements	**Shimmer in dB**	ASD	0.75		
		NTD	0.77		
		Pearson		0.36	0.12
	Shimmer in Percent	ASD	7.36		
		NTD	7.74		
		Pearson		0.48	0.03*
	Amplitude Perturbation Quotient	ASD	7.91		
		NTD	8.04		
		Pearson		0.53	0.02*
	Smoothed Amplitude Perturbation Quotient	ASD	22.68		
		NTD	20.10		
		Pearson		0.40	0.08
	Peak to Peak Amplitude Variation	ASD	76.61		
		NTD	37.38		
		Pearson		0.05	0.83
Noise-Related Measurements	**Noise to Harmonics Ratio**	ASD	0.28		
		NTD	0.27		
		Pearson		-0.13	0.58
	Voice Turbulence Index	ASD	0.18		
		NTD	0.12		
		Pearson		0.03	0.90
	Soft Phonation Index	ASD	19.39		
		NTD	21.88		
		Pearson		-0.23	0.34
Tremor-Related Measurements	**Amplitude Frequency**	ASD	4.37		
		NTD	1.77		
		Pearson		0.35	0.13
	f0 Tremor Intensity Index	ASD	1.40		
		NTD	0.90		
		Pearson		0.20	0.40
	Amplitude Tremor Intensity Index	ASD	4.28		
		NTD	3.98		
		Pearson		0.06	0.81
Voice Break-Related Measurements	**Degree of Voice Breaks**	ASD	74.32		
		NTD	75.01		
		Pearson		0.31	0.18
	Number of Voice Breaks	ASD	19.00		
		NTD	18.00		
		Pearson		-0.23	0.34
Sub-Harmonic-Related Measurements	**Degree of Sub-Harmonics**	ASD	1.07		
		NTD	2.40		
		Pearson		0.15	0.54
	Number of Sub-harmonic Segments	ASD	1.38		
		NTD	3.17		
		Pearson		0.12	0.61
Voice Irregularity-Related	**Degree of Voiceless**	ASD	73.26		
		NTD	73.96		
		Pearson		0.39	0.09

Measurements	**Number of Unvoiced Segments**	ASD	365.88		
		NTD	370.50		
		Pearson		0.39	0.09
	Number of Segments Computed	ASD	499.38		
		NTD	501.00		
		Pearson		0.11	0.65
	Total Number Detected Pitch Periods	ASD	861.75		
		NTD	699.58		
		Pearson		-0.42	0.06

[Results of the correlation between the Strain parameter for the task Story 1, as rated by the Expert Group using the CAPE-V and the results of the voice analysis from the MDVP]
*denotes statistically significant correlation, $p<0.050$

Table 57. Correlations from the Expert Group Overall Severity Rating and the Voice Analysis of Story 2

	Parameter	**Group**	**Mean Value**	**Pearson r**	**Significance**
CAPE-V Measurement	**Overall Severity**	ASD	17.08	n/a	n/a
		NTD	14.62	n/a	n/a
Fundamental Frequency Measurements	**Average Fundamental Frequency**	ASD	260.41		
		NTD	226.28		
		Pearson		0.15	0.53
	Mean Fundamental Frequency	ASD	251.64		
		NTD	222.31		
		Pearson		0.09	0.72
	Average Pitch Period	ASD	4.09		
		NTD	4.58		
		Pearson		-0.10	0.67
	Highest Fundamental Frequency	ASD	436.41		
		NTD	339.18		
		Pearson		0.13	0.59
	Lowest Fundamental Frequency	ASD	128.23		
		NTD	143.06		
		Pearson		-0.06	0.82
	Standard Deviation of f0	ASD	51.20		
		NTD	29.48		
		Pearson		0.45	0.05*
	Phonatory f0 range in Semi-Tones	ASD	23.38		
		NTD	17.17		
		Pearson		0.14	0.55
Short- and Long-Term Frequency Perturbation Measurements	**Absolute Jitter**	ASD	120.05		
		NTD	141.59		
		Pearson		0.45	0.05*
	Jitter Percent	ASD	2.97		
		NTD	3.08		
		Pearson		0.55	0.01*
	Relative Average Perturbation	ASD	1.69		
		NTD	1.69		
		Pearson		0.41	0.07
	Pitch Perturbation Quotient	ASD	1.95		
		NTD	1.98		
		Pearson		0.49	0.03*
	Smoothed Pitch Perturbation Quotient	ASD	5.24		
		NTD	5.22		
		Pearson		0.41	0.07
	Fundamental Frequency Variation	ASD	19.73		
		NTD	13.48		
		Pearson		0.45	0.05*

Short- and Long-Term Amplitude Perturbation Measurements	**Shimmer in dB**	ASD	0.82		
		NTD	0.78		
		Pearson		0.20	0.40
	Shimmer in Percent	ASD	7.69		
		NTD	7.72		
		Pearson		0.22	0.34
	Amplitude Perturbation Quotient	ASD	8.40		
		NTD	7.97		
		Pearson		-0.21	0.38
	Smoothed Amplitude Perturbation Quotient	ASD	26.37		
		NTD	20.21		
		Pearson		-0.04	0.86
	Peak to Peak Amplitude Variation	ASD	54.36		
		NTD	39.28		
		Pearson		0.00	0.99
Noise-Related Measurements	**Noise to Harmonics Ratio**	ASD	0.25		
		NTD	0.25		
		Pearson		0.39	0.09
	Voice Turbulence Index	ASD	0.14		
		NTD	0.19		
		Pearson		-0.17	0.49
	Soft Phonation Index	ASD	19.60		
		NTD	20.05		
		Pearson		-0.18	0.44
Tremor-Related Measurements	**Amplitude Frequency**	ASD	3.87		
		NTD	4.37		
		Pearson		0.25	0.38
	f0 Tremor Intensity Index	ASD	1.95		
		NTD	0.66		
		Pearson		0.07	0.77
	Amplitude Tremor Intensity Index	ASD	5.64		
		NTD	3.88		
		Pearson		0.04	0.87
Voice Break-Related Measurements	**Degree of Voice Breaks**	ASD	67.89		
		NTD	72.10		
		Pearson		0.02	0.93
	Number of Voice Breaks	ASD	19.12		
		NTD	21.33		
		Pearson		-0.17	0.49
Sub-Harmonic Related Measurements	**Degree of Sub-Harmonics**	ASD	1.72		
		NTD	3.65		
		Pearson		0.28	0.23
	Number of Sub-harmonic Segments	ASD	2.50		
		NTD	2.86		
		Pearson		0.15	0.54
Voice	**Degree of**	ASD	69.30		

Irregularity-Related Measurements	**Voiceless**	NTD	69.64		
		Pearson		0.12	0.62
	Number of Unvoiced Segments	ASD	346.00		
		NTD	348.17		
		Pearson		0.13	0.560
	Number of Segments Computed	ASD	499.25		
		NTD	500.08		
		Pearson		0.17	0.48
	Total Number Detected Pitch Periods	ASD	1066.62		
		NTD	851.17		
		Pearson		0.03	0.90

[Results of the correlation between the Overall Severity parameter for the task Story 2, as rated by the Expert Group using the CAPE-V and the results of the voice analysis from the MDVP]

Table 58. Correlations from the Expert Group Roughness Rating and the Voice Analysis of Story 2

	Parameter	**Group**	**Mean Value**	**Pearson r**	**Significance**
CAPE-V Measurement	**Roughness**	ASD	7.55	n/a	n/a
		NTD	9.40	n/a	n/a
Fundamental Frequency Measurements	**Average Fundamental Frequency**	ASD	260.41		
		NTD	226.28		
		Pearson		-0.12	0.61
	Mean Fundamental Frequency	ASD	251.64		
		NTD	222.31		
		Pearson		-0.20	0.39
	Average Pitch Period	ASD	4.09		
		NTD	4.58		
		Pearson		0.19	0.42
	Highest Fundamental Frequency	ASD	436.41		
		NTD	339.18		
		Pearson		-0.15	0.52
	Lowest Fundamental Frequency	ASD	128.23		
		NTD	143.06		
		Pearson		-0.32	0.17
	Standard Deviation of f0	ASD	51.20		
		NTD	29.48		
		Pearson		0.52	0.20*
	Phonatory f0 range in Semi-Tones	ASD	23.38		
		NTD	17.17		
		Pearson		0.25	0.30
Short- and Long-Term Frequency Perturbation Measurements	**Absolute Jitter**	ASD	120.05		
		NTD	141.59		
		Pearson		0.69	0.00*
	Jitter Percent	ASD	2.97		
		NTD	3.08		
		Pearson		0.66	0.00*
	Relative Average Perturbation	ASD	1.69		
		NTD	1.69		
		Pearson		0.57	0.01*
	Pitch Perturbation Quotient	ASD	1.95		
		NTD	1.98		
		Pearson		0.66	0.00*
	Smoothed Pitch Perturbation Quotient	ASD	5.24		
		NTD	5.22		
		Pearson		0.71	0.00*
	Fundamental Frequency Variation	ASD	19.73		
		NTD	13.48		
		Pearson		0.61	0.00*

Short- and Long-Term Amplitude Perturbation Measurements	**Shimmer in dB**	ASD	0.82		
		NTD	0.78		
		Pearson		0.21	0.36
	Shimmer in Percent	ASD	7.69		
		NTD	7.72		
		Pearson		0.41	0.08
	Amplitude Perturbation Quotient	ASD	8.40		
		NTD	7.97		
		Pearson		-0.02	0.94
	Smoothed Amplitude Perturbation Quotient	ASD	26.37		
		NTD	20.21		
		Pearson		-0.06	0.82
	Peak to Peak Amplitude Variation	ASD	54.36		
		NTD	39.28		
		Pearson		-0.10	0.67
Noise-Related Measurements	**Noise to Harmonics Ratio**	ASD	0.25		
		NTD	0.25		
		Pearson		0.35	0.13
	Voice Turbulence Index	ASD	0.14		
		NTD	0.19		
		Pearson		0.06	0.81
	Soft Phonation Index	ASD	19.60		
		NTD	20.05		
		Pearson		-0.00	0.99
Tremor-Related Measurements	**Amplitude Frequency**	ASD	3.87		
		NTD	4.37		
		Pearson		0.49	0.03*
	f0 Tremor Intensity Index	ASD	1.95		
		NTD	0.66		
		Pearson		-0.20	0.39
	Amplitude Tremor Intensity Index	ASD	5.64		
		NTD	3.88		
		Pearson		-0.15	0.54
Voice Break-Related Measurements	**Degree of Voice Breaks**	ASD	67.89		
		NTD	72.10		
		Pearson		0.15	0.52
	Number of Voice Breaks	ASD	19.12		
		NTD	21.33		
		Pearson		0.35	0.13
Sub-Harmonic-Related Measurements	**Degree of Sub-Harmonics**	ASD	1.72		
		NTD	3.65		
		Pearson		0.60	0.01*
	Number of Sub-harmonic Segments	ASD	2.50		
		NTD	2.86		
		Pearson		0.46	0.04*
Voice	**Degree of**	ASD	69.30		

Irregularity-Related Measurements	**Voiceless**	NTD	69.64		
		Pearson		0.03	0.89
	Number of Unvoiced Segments	ASD	346.00		
		NTD	348.17		
		Pearson		0.04	0.86
	Number of Segments Computed	ASD	499.25		
		NTD	500.08		
		Pearson		0.24	0.31
	Total Number Detected Pitch Periods	ASD	1066.62		
		NTD	851.17		
		Pearson		-0.23	0.33

[Results of the correlation between the Roughness parameter for the task Story 2, as rated by the Expert Group using the CAPE-V and the results of the voice analysis from the MDVP]
*denotes statistically significant correlation, p<0.050

Table 59. Correlations from the Expert Group Strain Rating and the Voice Analysis of Topic of Interest

	Parameter	**Group**	**Mean Value**	**Pearson r**	**Significance**
CAPE-V Measurement	**Strain**	ASD	8.57	n/a	n/a
		NTD	5.43	n/a	n/a
Fundamental Frequency Measurements	**Average Fundamental Frequency**	ASD	313.55		
		NTD	233.84		
		Pearson		0.63	0.00*
	Mean Fundamental Frequency	ASD	302.99		
		NTD	230.10		
		Pearson		0.61	0.01*
	Average Pitch Period	ASD	3.47		
		NTD	4.56		
		Pearson		-0.46	0.05*
	Highest Fundamental Frequency	ASD	487.16		
		NTD	355.43		
		Pearson		0.50	0.03*
	Lowest Fundamental Frequency	ASD	167.43		
		NTD	136.51		
		Pearson		0.02	0.92
	Standard Deviation of f0	ASD	59.33		
		NTD	29.17		
		Pearson		0.74	0.00*
	Phonatory f0 range in Semi-Tones	ASD	19.57		
		NTD	18.42		
		Pearson		0.32	0.18
Short- and Long-Term Frequency Perturbation Measurements	**Absolute Jitter**	ASD	94.30		
		NTD	133.61		
		Pearson		-0.23	0.34
	Jitter Percent	ASD	2.76		
		NTD	3.02		
		Pearson		0.18	0.46
	Relative Average Perturbation	ASD	1.58		
		NTD	1.77		
		Pearson		0.14	0.56
	Pitch Perturbation Quotient	ASD	1.82		
		NTD	1.99		
		Pearson		0.14	0.56
	Smoothed Pitch Perturbation Quotient	ASD	5.42		
		NTD	4.86		
		Pearson		0.43	0.07
	Fundamental Frequency Variation	ASD	18.37		
		NTD	11.96		
		Pearson		0.59	0.01*

Short- and Long-Term Amplitude Perturbation Measurements	**Shimmer in dB**	ASD	0.71		
		NTD	0.72		
		Pearson		0.23	0.34
	Shimmer in Percent	ASD	6.80		
		NTD	6.98		
		Pearson		0.23	0.35
	Amplitude Perturbation Quotient	ASD	7.51		
		NTD	7.40		
		Pearson		0.30	0.22
	Smoothed Amplitude Perturbation Quotient	ASD	21.57		
		NTD	19.42		
		Pearson		0.23	0.35
	Peak to Peak Amplitude Variation	ASD	46.27		
		NTD	40.80		
		Pearson		0.21	0.40
Noise-Related Measurements	**Noise to Harmonics Ratio**	ASD	0.27		
		NTD	0.25		
		Pearson		0.55	0.01*
	Voice Turbulence Index	ASD	0.20		
		NTD	0.31		
		Pearson		0.32	0.18
	Soft Phonation Index	ASD	15.94		
		NTD	25.27		
		Pearson		-0.30	0.21
Tremor-Related Measurements	**Amplitude Frequency**	ASD	3.69		
		NTD	3.94		
		Pearson		-0.18	0.47
	f0 Tremor Intensity Index	ASD	1.97		
		NTD	1.11		
		Pearson		0.13	0.62
	Amplitude Tremor Intensity Index	ASD	6.68		
		NTD	4.07		
		Pearson		0.21	0.39
Voice Break-Related Measurements	**Degree of Voice Breaks**	ASD	62.59		
		NTD	65.45		
		Pearson		0.08	0.74
	Number of Voice Breaks	ASD	32.34		
		NTD	26.00		
		Pearson		0.80	0.74
Sub-Harmonic-Related Measurements	**Degree of Sub-Harmonics**	ASD	1.63		
		NTD	2.86		
		Pearson		-0.19	0.43
	Number of Sub-harmonic Segments	ASD	2.86		
		NTD	5.25		
		Pearson		-0.28	0.25
Voice	**Degree of**	ASD	58.85		

Irregularity -Related Measurements	**Voiceless**	NTD	61.42		
		Pearson		0.13	0.61
	Number of Unvoiced Segments	ASD	279.57		
		NTD	298.83		
		Pearson		0.10	0.68
	Number of Segments Computed	ASD	461.86		
		NTD	488.25		
		Pearson		-0.04	0.87
	Total Number Detected Pitch Periods	ASD	1405.57		
		NTD	10.56.00		
		Pearson		0.19	0.44

[Results of the correlation between the Strain parameter for the task Topic of Interest, as rated by the Expert Group using the CAPE-V and the results of the voice analysis from the MDVP]
*denotes statistically significant correlation, p<0.050

Table 60. Profile Summary for Children with ASD

Area of Speech	**Characteristic for Children with ASD**	**Statistically Significant Task(s)**
Duration & Timing	Decreased Maximum Phonation Time	[f], $p<0.03$
	Increased utterance length	No statistically significant tasks
	Increased pause length	No statistically significant tasks
	Increased vowel length	[i] of "pea," $p<0.00$
	Decreased number of syllable repetitions in AMR and SMR tasks	[pʌ], $p<0.02$ [tʌ], $p<0.01$ [kʌ], $p<0.02$
Acoustic Measures	Lower formant values	[a] F3, $p<0.04$ [i] of "pea" F2, $p<0.05$ [i] of "pea" F3, $p<0.01$ [i] of "tea" F2, $p<0.01$ [i] of "tea" F3, $p<0.01$
	Lower pitch values	[i], $p<0.04$
Voice Measures	Increased Average Fundamental Frequency	Happy Birthday, $p<0.03$ Story 1, $p<0.02$ Topic of Interest, $p<0.01$
	Decreased Average Pitch Period	Happy Birthday, $p<0.04$ Story 1, $p<0.04$ Topic of Interest, $p<0.02$
	Increased Highest Fundamental Frequency	Happy Birthday, $p<0.02$ Story 1, $p<0.04$ Story 2, $p<0.04$ Topic of Interest, $p<0.05$
	Increased Standard Deviation of f0	Story 1, $p<0.02$ Story 2, $p<0.03$ Topic of Interest, $p<0.01$
	Decreased Absolute Jitter	Counting, $p<0.01$ Happy Birthday, $p<0.01$ Topic of Interest, $p<0.01$
	Decreased Relative Average Perturbation	Counting, $p<0.05$
	Increased Fundamental Frequency Variation	Topic of Interest, $p<0.02$
	Increased Smoothed Amplitude Perturbation Quotient	Story 2, $p<0.05$
	Increased Peak-to-Peak Amplitude Variation	Story 2, $p<0.00$
Perceptual Measures	Mildly deviant level of Roughness	No statistically significant tasks
	Decreased Strain	No statistically significant tasks

	Atypical prosody	No statistically significant tasks
	Inconsistent nasality	No statistically significant tasks

[Summary of statistically significant variables]

Figures

Figure 1. Mean Maximum Phonation Times

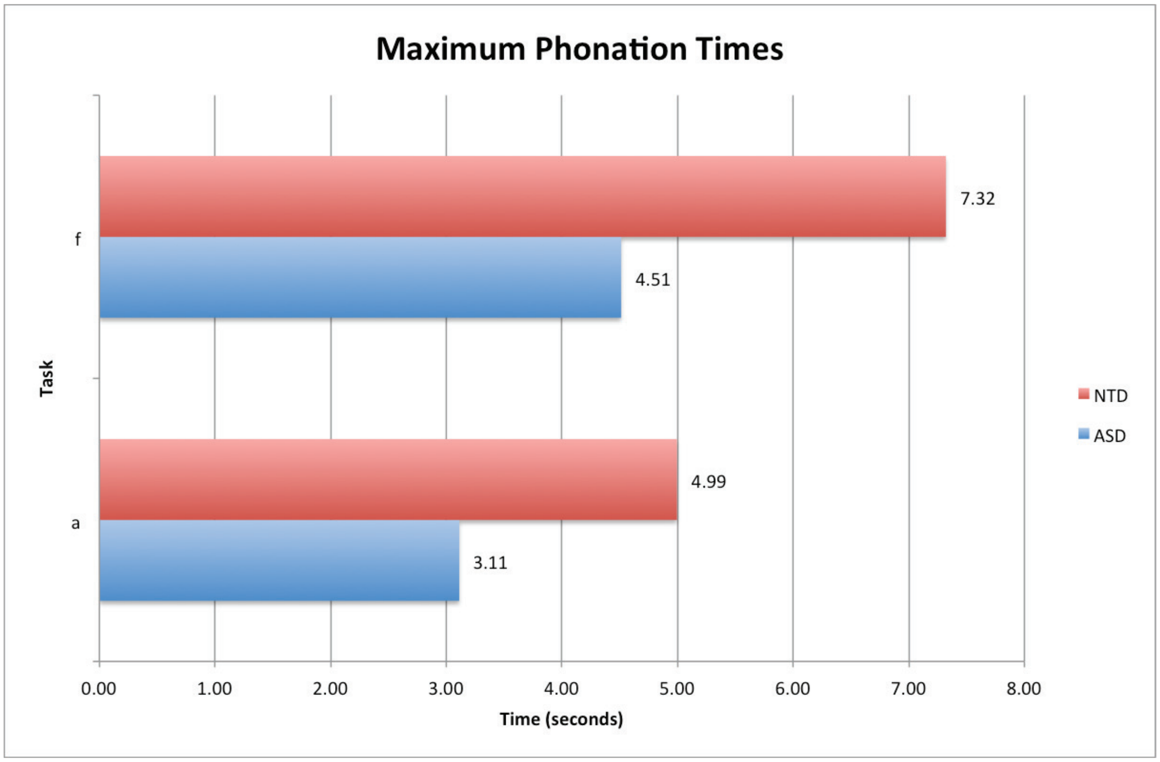


Figure 2. Results of Novice Group CAPE-V Ratings for Counting 1-10, Overall Severity

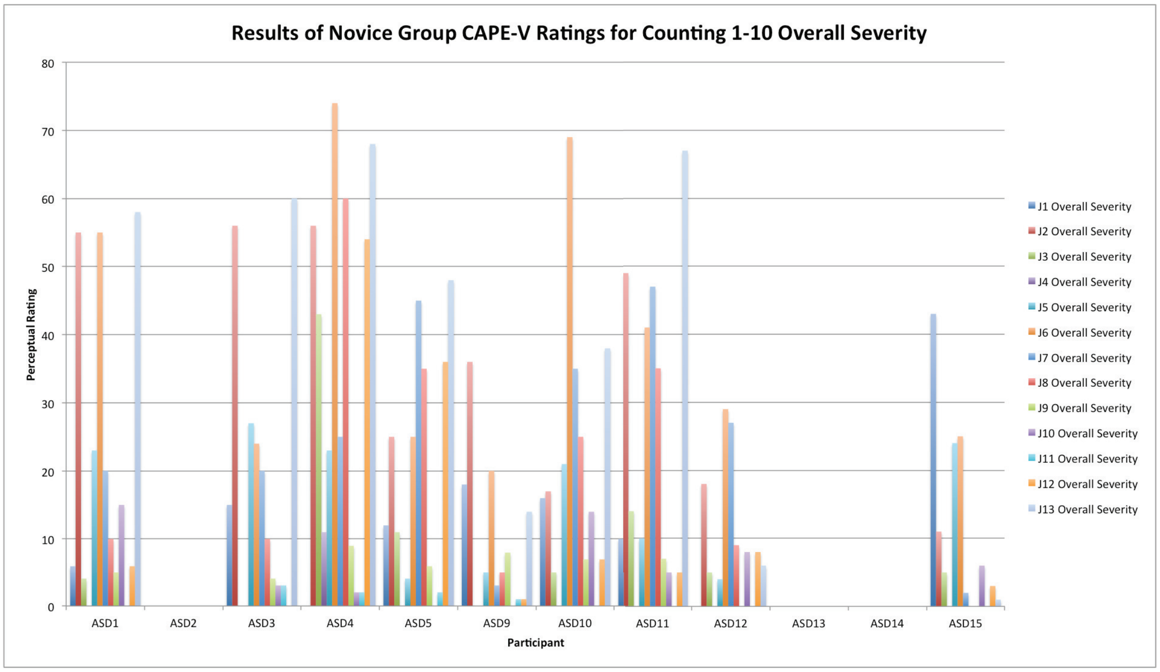
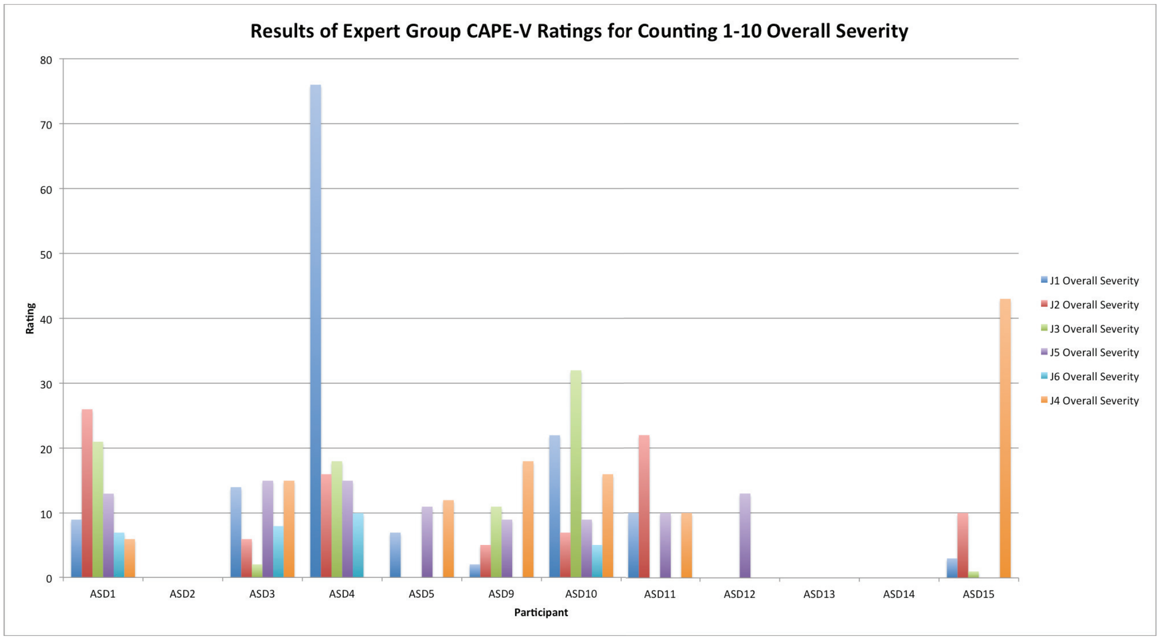


Figure 3. Results of Expert Group CAPE-V Ratings for Counting 1-10, Overall Severity



APPENDIX A

CAPE-V HISTORY FORM

1. What is your gender?

2. What is your age?

3. Where were you born?

4. Where did you grow up?

5. What is your native language?

6. Do you speak any other languages? If so, which ones?

7. Do you have a hearing impairment? If so, what type?

8. If you have hearing impairment, do you wear a hearing aid or have any corrected form of hearing?

9. Have you ever used the CAPE-V before?
    1. If so, how many times have you used it?

10. Have you ever performed a voice evaluation, either in the clinic or in your off-campus placements?
    1. If so, how many voice evaluations have you performed?

11. Do you have any formal training in voice, e.g., singing?
    1. If so, for how many years were you trained?

12. Do you have any formal training in music, e.g., playing an instrument?
    1. If so, for how many years were you trained?
    2. What instrument(s) is your training in?

10\. Do you have a family member or an acquaintance with a voice difference or voice disorder? If so, how long have you known them and what type of difference or problem do they have? Please describe.

Appendix B

TESTING PROTOCOL AND DIRECTIONS

Participant Name: **Date:**
DOB: **Age:** **ID:**

Speech Task		Completed	Notes
Imitated Speech **Please note: each of these speech tasks should be completed three times**	1. [a] prolongation		
	2. [f] prolongation		
	3. [i]		
	4. “pea tea key”		**Picture? Y N**
	5. AMR: [pʌ]		
	6. AMR: [tʌ]		
	7. AMR: [kʌ]		
	8. SMR: [pʌtʌkʌ]		
Elicited Speech	9. Counting 1-10		**Picture? Y N**
	10. Sing “Happy Birthday”		
Spontaneous Speech	11. Story (Giraffe & Elephant)		
	12. Story (Bunnies)		
	13. Topic of Interest		

Verbal directions:

1 + 2) [a] & [f] prolongation

“I want you to say this sound for as long as you can. Watch me and see how I do it, then it’s your turn.”

Take a breath, and then model productions of [a] that are as long as you can comfortably produce. Complete this task three times, then repeat with [f].

Prompt for longer productions as necessary. Aim for all child productions to be greater than 2 seconds in length.

3). [i]

“Now, I’m going to say a sound, and then it’s your turn to say the same sound. Listen to me first, then it’s your turn.” Produce the vowel [i], as in “feet,” for approximately three seconds. Encourage the child to produce the vowel for 2 seconds. Repeat three times.

4). “pea tea key”

“Let’s put some different sounds together now. I’m going to say some words, then you can say the same words.”

Model the phrase “pea tea key.” Have the child imitate you, then repeat this procedure two more times.

If the child experiences difficulty sequencing the task, provide them with the picture cue and note its usage.

5 + 6 + 7 + 8). AMR: [pʌ]

“Now let’s see how fast we can say these sounds. I’m going to say this sound as fast as I can, as many times I can. Like this [model]. Now you try.”

Model production of [pʌpʌpʌpʌpʌpʌpʌpʌpʌ] as smoothly as you can. Encourage the child to produce a similar repetition. Repeat three times. Continue with [tʌ], then [kʌ], and finally, [pʌtuʌkʌ].

9). Counting 1-10

“Show me how you count from 1-10.”

Provide child with picture cues, if necessary and record.

10). Sing “Happy Birthday”

“I’d love to hear how you sing. Let’s pretend it’s XXX’s birthday (pick child, relevant other, toy, etc.) Sing me the happy birthday song.”

11). Story (Giraffe & Elephant) These stories are from the ENNI, and below are their directions for administration.

Show the child the binder. Hold it in such a way that you cannot see the pictures, but they are clearly in view of the child.

“I have some pictures that tell a story. First I’ll show you all the pictures and we’ll go back to the beginning of the story, and then I want you to look at the pictures and tell me the story that you see in the pictures. I won’t be able to see the pictures so you need to tell me the story really well so I can understand it. Okay?”

- If the child has trouble getting started:
  - You say: How would you start your story? [pause]
  - If that doesn’t work:
    - You say: Would you start “one day”, or “once upon a time?”
  - If child says “one day/once upon a time” and stops:
    - You say: “oh”, [repeat what child said]. [pause]
  - If child still doesn’t respond or says “don’t know”:
    - You say: What happens in the story?
  - If child says nothing or “don’t know”:
    - You say: Look at the pictures – what do you think is happening in the story?
  - If child still can’t get started or go on:
    - You say: Let’s try the next page.
  - TERMINATE TESTING IF THE CHILD CANNOT GET STARTED AFTER TWO PAGES OF THE FIRST TEST STORY.
- If the child mumbles or says something you don’t understand:
  - You say: I didn’t hear that – could you repeat that? [You can also remind the child after s/he repeats to talk in a clear voice so that the microphone can hear the story.]
- If child wants you to label something in the picture:
  - You say: What do YOU think?
- If child says nothing or “don’t know”:
  - You say: This is your story – you get to decide.

[pause]

- If the child is still stuck on a label:
    - You say: Let's not worry about that – tell me the rest of your story.
- Any time the child gets stuck in the story:
    - Look at the child expectantly and wait for the child to continue. Be sure and give the child time to respond. Don't yield to the pressure to fill in the silence. Only give prompts when it appears that the child is not going to say anything. A good strategy is to repeat the last thing the child said rather than giving more explicit help. (Directions from ENNI)

12). Story (Bunnies)

Flip the binder over, and present it to the child as a new story. Again, hold it in such a way that the pictures are not visible to you but are clearly in view of the child.

"Now I have some more picture stories. First I'll show you all the pictures. Then we'll go back to the beginning of the story, and then I want you to look at the pictures and tell me the story that you see in the pictures. I won't be able to see the pictures so you need to tell me the story really well so I can understand it. Okay?"

- If the child has trouble getting started:
    - You say: How would you start your story? [pause]
    - If that doesn't work:
        - You say: Would you start "one day", or "once upon a time?"
    - If child says "one day/once upon a time" and stops:
        - You say: "oh", [repeat what child said]. [pause]
    - If child still doesn't respond or says "don't know":
        - You say: What happens in the story?
    - If child says nothing or "don't know":
        - You say: Look at the pictures – what do you think is happening in the story?
    - If child still can't get started or go on:
        - You say: Let's try the next page.
    - TERMINATE TESTING IF THE CHILD CANNOT GET STARTED AFTER TWO PAGES OF THE FIRST TEST STORY.
- If the child mumbles or says something you don't

understand:
  - You say: I didn’t hear that – could you repeat that? [You can also remind the child after s/he repeats to talk in a clear voice so that the microphone can hear the story.]
- If child wants you to label something in the picture:
  - You say: What do YOU think?
- If child says nothing or “don’t know”:
  - You say: This is your story – you get to decide. [pause]
- If the child is still stuck on a label:
  - You say: Let’s not worry about that – tell me the rest of your story.
- Any time the child gets stuck in the story:
  - Look at the child expectantly and wait for the child to continue. Be sure and give the child time to respond. Don’t yield to the pressure to fill in the silence. Only give prompts when it appears that the child is not going to say anything. A good strategy is to repeat the last thing the child said rather than giving more explicit help. (Directions from ENNI)

13). Topic of Interest
The child’s parents/guardians will have been asked to bring in a favorite toy or object that the child possesses. Place this object clearly in view of the child, or permit the child to hold it quietly on their lap. **Do not let the child bang the object on the table, chair, or any other hard surface that creates a noise.**
“What did you bring today? Tell me about it.”
Listen to the child’s speech, responding verbally only as absolutely necessary. Nod and use facial expressions to encourage the child to continue. We are aiming for capturing a minimum of 15 seconds of continuous spontaneous speech.

APPENDIX C

EXPERT GROUP CAPE-V QUALITATIVE COMMENTS

Judge Coding

Judge 1

Judge 2

Judge 3

Judge 4

Judge 5

Judge 6

Counting

- ASD1: choppy, awkward phrasing, vocal quality appears normal except for breathiness and slight roughness
- ASD1: omission of final consonant
- ASD4: increased rate, decreased duration, staccato, robotic
- ASD4: choppy, awkward phrasing
- ASD4: choppy/halting
- ASD5: I can't put my finger on it; the child sounds hypo until "nine," then sounds hypernasal.
- ASD10: decreased coordination with respiration ?apraxic or ataxic
- ASD10: rising pitch as counted
- ASD11: phono errors, vowel off in nine
- ASD15: said 4 louder with more emphasis, do/two
- NTD4: missing teeth?
- NTD5: lisp /s/
- NTD5: ha! This kiddo is being "funny" I think… I scored it as if he/she wasn't, but I'm guessing the "normal voice" is WNL
- NTD6: th, w/thr
- NTD14: fr/three
- NTD15: ?lisp, airy

Happy Birthday

- ASD1: difficulty regulating volume, phonology
- ASD3: hard onset on initial sounds
- ASD4: decreased coordination, ?? respiratory system & articulatory & phonatory systems. ?apraxia or ataxic
- ASD4: intonation/prosody off
- ASD5: phonological errors, difficulty coordinating phonation and respiration, even stress on words
- ASD5: ?hyponasal, but have one nasal to judge (Stephanie)
- ASD6: d/th, rate inconsistent
- ASD7: phonological errors, t/th, hard onset on Erica, stress on words off
- ASD9: low pitch, sounded as if at end of pitch range, even stress on words/flat
- ASD10: phonological errors
- NTD3: not a singer, little pitch range
- NTD4: laughing, burst of air phonology errors
- NTD6: I chose not to mark roughness or pitch because it was evident that the child was giggling.
- NTD7: d/th
- NTD8: breathiness could be laughing, t/th phonology
- NTD11: rapid rate, artic errors
- NTD12: flat, not a lot of variation in pitch but could have difficulty with singing
- NTD14: phonology, d/th

Story 1

- ASD4: choppy, awkward stress
- ASD4: rising pitch at wrong point in word/sentence, phonology
- ASD5: unintelligible at times
- ASD5: I did not score the “rrrr” @ 0:10 because I thought it was a sound effect or a way to buy time to think.
- ASD7: fluency- repetitions/revisions, stress off
- ASD8: choppy speech
- ASD9: phonology errors, ge/girl
- ASD10: pitch instability, may just be the “goofiness” when doing character voices
- ASD10: stress and prosody off
- ASD11: lateral lisp, choppy prosody/awkward phrasing

- ASD11: Again, I can’t tell if the voice stoppages are due to voice control, expressive language, artic, breath support, etc.
- ASD11: choppy
- ASD12: sounds congested, could be temporary, sounds out of breath
- ASD12: fluency, ele-elephant, that-that-that
- ASD15: she prolongation, repetition
- NTD2: choppy halting speech, prosody off, destress final consonant
- NTD3: monopitch, appears apathetic
- NTD3: choppy
- NTD8: airy /s/, mild distorted /r/ in girl
- NTD9: halting, breath at end of sentence
- NTD10: slow, halting but could be correlated to story presentation, w/r
- NTD10: mild pitch instability at beginning of phrase
- NTD12: hear breathiness @ ends and beginnings of sentences
- NTD14: very juvenile
- NTD14: phonology
- NTD15: pragmatically off. He sounds like a weenie (if typical) or ASD
- NTD15: choppy, hard onsets

Story 2

- ASD3: stress on words off/ inconsistent
- ASD4: distorts /z/ to /zʌ/, repetitions, fluency
- ASD5: some unintelligible
- ASD6: sounds like stresses words at ends of phrases/sentences
- ASD7: repetitions, w/rabbit, intonation/prosody off
- ASD8: singing for a bit there, secondary to prosody not necessary vocal characteristics
- ASD8: sings part of what saying
- ASD9: increased rate within some words
- ASD9: language errors, final consonant deletion
- ASD11: fluency- choppy, grammatical errors, growed, t/d voicing stop
- ASD12: slight rising pitch @ end, airiness in /s/, stress off
- ASD15: there-there, even stress on words
- NTD2: choppy halting speech
- NTD3: prosody/intonation off
- NTD10: den, then; dis, this; dysfluent at times

  - NTD12: interjections, uhm
  - NTD13: rough/strained voice but otherwise WNL. Sounds like a kid who yells a lot
  - NTD14: phono errors
  - NTD15: hard attack on /t/s, audible inhalations

Topic of Interest

  - ASD4: poor pitch control & monopitch, seems odd to write both, but you could tell he's more monopitch most of the time but is trying to produce a question- and this is not well controlled when he attempts it
  - ASD4: rising pitch within words (name), articulation off, stress even, epenthesis in name
  - ASD6: word repetitions and, and, and, rate increase and decreased intelligibility
  - ASD8: prosody off, rising intonation at wrong times
  - ASD10: rapid rate of speech, repetitions, I like, I like
  - ASD 11: lateral lisp, choppy prosody, vocal quality appears to be okay despite these other features
  - ASD11: phonological errors, prosody off
  - ASD11: I cannot tell if he is stopping/restarting the narrative or if he is having a pitch break or voice cutting out
  - ASD15: repetitions, grammar, builded
  - NTD1: revisions, interjection
  - NTD2: halting, interjections
  - NTD4: phrase repetitions, difficulty with vocabulary, choppy/hesitant speech ca-candy
  - NTD8: stress at ends of sentences seems off
  - NTD10: articulation errors, fluency f-f
  - NTD12: sounds normal but uninflected
  - NTD14: phonology, pronoun errors
  - NTD15: revisions, prolongation, right

- Other
  - Volume/intensity: hard to judge because an artifact of how close the subject was to the mic
  - Age: some prosody is pathology or not based on age so this was tough
  - Prosody: included phrasing & structure, not just voice

    - Pitch: very difficult to judge during counting & singing

Note that comments have been transcribed to reflect the comments as provided by the judge, i.e., no editing has occurred.

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