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Differences between the acoustic parameters of prosody in speakers with asd and typically developing speakers ages three to six

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DIFFERENCES BETWEEN THE ACOUSTIC PARAMETERS OF PROSODY IN SPEAKERS WITH ASD AND TYPICALLY DEVELOPING SPEAKERS AGES THREE TO SIX

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ABSTRACT

The present study was designed to compare the acoustic parameters of prosody of children between the ages of three and six with Autism Spectrum Disorder (ASD to age matched typically developing (TD) speakers. The acoustic parameters of prosody examined were fundamental frequency (f0), intensity, speech rate, and speech rhythm. Analyzing the acoustic features of atypical expressive prosody in speakers with ASD would provide more detailed and defined information regarding the nature of the prosodic abnormality in these individuals to guide clinicians in providing a more concentrated focus for intervention. Speech samples were obtained from ten English-speaking, monolingual children (5 ASD, 5 TD) between the ages of three and six. The speech samples were analyzed for various measurements of f0, intensity, speech rate, and speech rhythm to determine differences.

Results showed that, of the ten prosodic variables analyzed, five of them were significantly different between ASD and TD speakers: %V, mean f0, f0 standard deviation, intensity range, and intensity standard deviation. Specifically, TD speakers had a higher %V, f0 mean, intensity range, and intensity standard deviation, while ASD speakers had a higher f0 standard deviation.

These findings in relation to previous, similar research, suggest that the prosodic features of preschool age children with ASD change with increasing age. Therefore, it is essential that clinicians are aware of ages in which prosodic deficits tend to appear so that intervention can begin at the appropriate age for each child and potential social barriers can be minimized or prevented.

CHAPTER 1.
INTRODUCTION

Autism spectrum disorder (ASD) is defined as a developmental disability characterized by a range of conditions resulting in deficits in communication and social interaction. Since ASD is a spectrum disorder, the behaviors that make up the ASD diagnosis are present in varying degrees in each individual. Before 2013, Asperger Syndrome (AS) and high functioning autism (HFA) were considered two separate diagnoses with the main difference being that individuals with HFA were thought to show a delay in early language development while individuals with AS typically did not. In 2013, The Diagnostic and Statistical Manual of Mental Disorders (5^{th} ed.; DSM-5; American Psychiatric Association, 2013) replaced Asperger Syndrome and other pervasive developmental disorders with the term "Autism Spectrum Disorder."

ASD is typically diagnosed by a specialist in accordance with DSM-5. The DSM-5 states that an individual must meet the specific diagnostic criteria in order to be given an official ASD diagnosis. The first diagnostic criterion includes the presence of persistent deficits in social communication and social interaction across multiple contexts, including deficits in social-emotional reciprocity, nonverbal communicative behaviors used during social interactions, and the ability to develop, maintain, and understand relationships. The second diagnostic criterion includes the presence of restricted, repetitive patterns of behavior, interests, or activities demonstrated by at least two of the following behaviors: insistence on sameness, restricted interests, hyper- or hypo-sensitivity to sensory input, and repetitive speech, motor movements, or use of objects. The next DSM-5 criterion states that symptoms must be present in the early stages of development and cause significant impairments in the ability to function socially and occupationally. Finally, the symptoms present must not be better explained by an intellectual disability or global developmental delay (American Psychiatric Association, 2013).

The prevalence of ASD continues to increase, and according to the Centers for Disease Control and Prevention (2018), 1 in 59 children have an ASD diagnosis. Although advances in research throughout the past century have provided a better understanding of ASD, there still remains numerous unanswered questions. With ASD diagnoses occurring more frequently, it is crucial for researchers to obtain as much information regarding ASD as possible so that parents and specialists may have a clear understanding of the disorder as well as knowledge concerning the best forms of treatment.

Though not directly stated in the DSM-5 diagnostic criteria, atypical prosody in verbal communication is considered a principal feature of ASD. In fact, The American Speech-Language-Hearing Association recommends that speech prosody be assessed during a speech and language evaluation when diagnosing individuals with ASD; however, according to Peppé, McCann, Gibbon, O'Hare, and Rutherford (2006), prosodic deficits are infrequently addressed by speech-language pathologists despite the fact that speakers are negatively impacted by prosodic deficits.

Prosody is the study of the stress, rhythm, intonation, and loudness of speech. Prosody is imperative because it contributes to the meaning of speech production. Prosody has the power to express the meaning of an utterance and reveal the speaker's emotional state depending on the context and circumstances in which the utterance is spoken. Perceptually, prosody consists of the way listeners perceive pitch, loudness, rhythm, and rate of speech. The acoustic correlates of pitch and loudness are frequency and intensity, and rhythm can be measured acoustically by phoneme and syllable duration (Mannell, 2007). Fundamental frequency is the rate in which the vocal folds vibrate. The average adult male fundamental frequency is 125 Hz while the average adult female fundamental frequency is 225 Hz. The average fundamental frequency of a child ranges from approximately 300 to 500 Hz. As children age, typically, their fundamental frequency will decrease. Variations in fundamental frequency while speaking are typical and contribute to the natural, melodic pattern of speech. Intensity refers to the size of the pulsations of the vocal folds and is perceived as loudness by listeners. The level of intensity is controlled by the force of the air through the lungs and through the vocal folds. Variations in loudness allow speakers to conform to background noise, express their emotional state, and portray the true meaning of an utterance. Rhythm in speech consists of the timing, placement of stress, and amount and length of syllables. Typical rhythmic patterns in speech allow listeners to distinguish between words in an utterance and identify the important components of a message (Hegde, 2010).

When speakers have prosodic deficits, it may be challenging for them to portray meaning in their utterances, speak in a typical, melodic pattern, and emphasize the significant portions of a message. This may result in a communication barrier that can cause difficulties communicating and functioning in social situations. Having an efficient method of identifying prosodic deficits in speakers will allow clinicians to develop intervention plans to treat individuals with prosodic difficulties. Conducting an acoustic analysis of prosodic parameters may be an effective way to identify specific prosodic insufficiencies. Nonetheless, information regarding typical and atypical prosodic features is needed in order to distinguish between individuals with normal prosodic abilities and those without.

The present study was designed to examine the differences between the acoustic parameters of prosody in speakers with ASD and typically developing speakers. The literature review for this study is divided into two sections. First, previous research regarding the perceptual prosodic characteristics observed in both individuals with ASD and typically developing individuals will be discussed along with a comparison of the perceptual characteristics between the two groups and the limitations of perceptual measurement. Next, previous research regarding the acoustic parameters of prosody measured in both individuals with ASD and typically developing individuals will be discussed along with a comparison of the acoustic parameters between the two groups. A discussion of research limitations will be included as well as agreements and disagreements between studies.

Perceptual Characteristics in Individuals with ASD and Typically Developing Individuals

Numerous studies have described and compared the perceptual ratings of both typically developing speakers and speakers with ASD. There is no universal method or scale for obtaining perceptual ratings; therefore, the available research varies in the processes used to examine and compare prosody perceptually. Nadig and Shaw (2012) obtained conversational language samples from 15 school aged children with HFA and 13 typically developing age matched children. The language samples were rated by 32 Communication Sciences and Disorders Masters students using a perceptual rating scale containing the following components: pitch, pitch changes, rate, and overall rating. The pitch scale ranged from 1 to 7 with 1 being "low," 4 being "normal," and 7 being "high." The pitch changes scale ranged from 1 to 7 with 1 being "monotone," 4 being "normal," and 7 being "too variable." The rate scale ranged from 1 to 7 with 1 being "slow," 4 being "normal," and 7 being "fast." The overall rating scale ranged from 1 to 4 with 1 being "atypical" and 4 being "normal." The students rated the mean pitch of the typically developing participants 3.85, describing the average pitch of the typically developing participants as slightly below "normal." The students rated the mean pitch of participants with HFA 3.97, describing the average pitch of these participants as also slightly below "normal" but slightly higher than the mean pitch of the typically developing participants with no significant difference. The students rated the pitch range of the typically developing participants 3.81, describing their pitch range as slightly below "normal." The students rated the pitch range of participants with HFA 4.00, describing the pitch range of these participants as exactly "normal."

The pitch range rating results reveal that the HFA speakers produced more variable, or "sing son," speech but with no significant difference. The students rated the rate of speech of the typically developing participants 3.77, describing their rate of speech as slightly below "normal." The students rated the rate of speech of participants with HFA 4.15, describing the rate of speech of these participants as slightly above "normal." The rate of speech rating results reveal that the HFA speakers spoke faster than the typically developing speakers but with no significant difference. The students assigned an overall rating score of 3.23 to the typically developing participants, describing their overall speech as slightly below "normal." The students assigned an overall rating score of 2.76 to the participants with HFA, describing their overall speech as slightly more than halfway between atypical and normal. The overall speech rating results reveal a more atypical overall impression of speech prosody in the HFA speakers with a significant difference between the two groups. These results reveal that listeners may not be able to fully interpret atypical prosody perceptually as evidenced by similar ratings for both groups for pitch, pitch changes, and rate; therefore, an acoustic analysis may be a more efficient way to describe the exact differences in prosodic features of speakers with ASD and typically developing speakers.

Using a similar yet simpler method, Filipe, Frota, Castro, and Vicente (2014) elicited one-word utterances from 12 children with ASD and 17 typically developing children using the turn-end subtest of the Profiling Elements of Prosody in Speech-Communication (PEPS-C). 35 undergraduate students were recruited to rate the naturalness and typicality of the one-word responses using a scale ranging from 1 to 5 with 1 being considered "common" and 5 being considered "uncommon." The average score given to the children with ASD was 3.42, while the average score given to the typically developing children was 2.39. These results show that the children with ASD were perceived as sounding significantly more atypical than the typically developing children. These results are comparable to Nadig and Shaw's (2012) results that showed a significant difference in the ratings between the speakers with HFA and the typically developing speakers when their speech was rated on an overall scale judging their speech as "atypical" or "normal," while there were no significant differences judged between the pitch, pitch changes, and rate. This shows that, perceptually, listeners are able to distinguish speakers with ASD and HFA from typically developing speakers when asked to judge their speech based on typicality; however, it becomes more difficult for listeners to distinguish between the two groups when asked to judge prosodic components, such as pitch and rate, individually. This is where acoustic analysis may become more helpful and efficient than perceptual analysis since it enables researchers to separate the prosodic variables into individual components to analyze and compare.

The two previously mentioned articles use rating scales as their method of perceptually measuring prosodic ability. Although this is a common technique, researchers and clinicians are migrating towards the use of formal assessment tools to measure prosody more efficiently. The Profiling Elements of Prosody in Speech-Communication (Peppé, 2015) is a non-standardized assessment tool used to assess both expressive and receptive prosodic skills in adults and children ages four and older. Many studies concerning individuals with ASD have used The Profiling Elements of Prosody in Speech-Communication (PEPS-C) as a tool to describe the prosodic features of the ASD population. The assessment consists of 14 subtests with each individual subtest evaluating prosodic function and form. Receptive and expressive skills are evaluated for each function. According to the PEPS-C, there are six key functions of prosody in language: contrastive stress/focus, phrase stress, lexical stress, affect, boundary/chunking, and turn-end. Contrastive stress, or focus, allows speakers to emphasize the most important word or words in an utterance, and phrase stress allows speakers to differentiate two nouns from each other as opposed to producing a compound word. Lexical stress consists of producing a multisyllabic word with emphasis on a particular syllable in the word, and affect is the ability to produce an utterance or word with a particular emotion attached to it. Boundaries separate, or “chunk,” phrases in order to produce the appropriate meaning, and turn-end distinguishes a question from a statement. Auditory discrimination tasks and imitation tasks are included in the administration of the PEPS-C to evaluate prosodic form. The auditory discrimination tasks assess receptive prosodic skills, and the imitation tasks assess expressive prosodic skills. The PEPS-C is a useful instrument for assessing the prosodic skills of speakers with ASD and other disorders resulting in prosodic deficits.

Peppé, Cleland, Gibbon, O’Hare, and Castilla (2011) compare expressive prosody in a different way than the first two mentioned articles. Instead of using a ranking scale to perceptually measure prosodic ability, they use formal assessment tools to examine the participants’ ability to use prosody functionally as well as imitate prosody. Scores are compared between children with Asperger’s syndrome (AS,) children with high-function autism (HFA), typically developing children matched for chronical age (TD-CM), and typically developing children matched for lexical mental age (TD-LM). Participants with AS and participants with HFA are separated to differentiate between the type and degree of language impairment in the two groups. The participants were administered the British Picture Vocabulary Scale to determine lexical mental age, the Raven’s Coloured Matrices and Progressive Matrices to determine non-verbal ability, Profiling Elements of Prosody in Speech-Communication (PEPS-C) to assess their ability to use and understand prosody for six major communication functions, and the Clinical Evaluation of Language Fundamentals-Third Edition UK (CELF-3 UK; Semel, Wiig, & Secord, 2000) to evaluate expressive language ability. Following an analysis of the PEPS-C scores, the authors reveal that the participants with HFA score significantly lower than the TD-LM group on the assessment tasks that assessed contrastive stress, effect, short-item imitation, and long-item imitation, and the HFA group scored even more significantly lower than the TD-CM group on all PEPS-C assessment tasks. This reveals that the participants with HFA had lower prosodic abilities than the typically developing children matched for both chronological age and lexical mental age, with the typically developing children matched for chronological age scoring the highest of the three groups. The participants with AS scored significantly lower than the TD-LM group only on the long-item imitation task, and the AS group scored significantly lower than the TD-CM group on the long-item, short-item, and chunking tasks. This reveals that the participants with AS also had lower prosodic abilities than the typically developing children matched for both chronological age and lexical mental age. The HFA group scored significantly lower than the AS group on the affect, long-item imitation, short-item imitation, contrastive stress, and turn-end tasks. The chunking task was the only task that the AS group scored higher on than the HFA group, but this difference was not significant. These results show that children with HFA have more difficulty with the typical production of prosody than children with AS. This could be related to the idea that individuals with HFA usually show a delay in early language development while individuals with AS typically do not. The authors conclude that since both the HFA group and the AS group show difficulties with imitation, this could be an explanation to why the ASD population displays difficulty with prosody. Difficulty with imitating prosody could result in the inability to produce prosody naturally. They also suspect that since there was a more significant difference between scores when compared to groups matched for chronological age versus lexical mental age, prosodic deficits may be a result of a delay in maturity in individuals with ASD. This is problematic and clinically significant because this delay resulting in a deficit may lead to social difficulties; therefore, including prosody in the intervention for children with autism may minimize the social and pragmatic deficits that are often seen within the ASD population. Furthermore, having further insight into the specific nature of the prosodic deficits in children with ASD will allow clinicians to target prosodic deficits more precisely to maximize the results of intervention. Acoustic analysis of prosody may be an efficient way to gain further insight into the specific nature of the prosodic deficits in children with ASD.

Although there are numerous studies describing the perceptual differences of prosody between individuals with ASD and typically developing individuals, perceptual ratings and measurements are typically subjective and prone to inconsistencies. Obtaining and comparing acoustical data provides a more reliable and consistent method with data that can be used universally by researchers and clinicians. Analyzing the acoustic features of atypical expressive prosody would also provide more detailed and defined information regarding the nature of the prosodic abnormalities in individuals with ASD to guide clinicians in providing a more concentrated focus for intervention to maximize treatment results.

Acoustic Parameters in Individuals with ASD and Typically Developing Individuals

Different acoustic measures can be obtained using programs such as Praat or TF32 in order to objectively describe fundamental frequency, intensity, speech rate, and speech rhythm. Quantitative information regarding fundamental frequency, or F0, can be attained by computing the mean fundamental frequency as well as the fundamental frequency range and standard deviation. The mean F0 measure is obtained by calculating the average F0 value within each utterance, and the F0 range is obtained by calculating the difference between the maximum and minimum F0. The F0 standard deviation is obtained by calculating the standard deviation from F0 distributions across each utterance. Quantitative information regarding intensity can be attained by computing the intensity range and standard deviation. The intensity range is obtained by calculating the difference between the maximum and minimum intensity within each individual speaker, and the intensity standard deviation is obtained by calculating the standard deviation from intensity distributions across each utterance. Quantitative information regarding speech rate can be attained by computing articulation rate, the number of syllables per second. Finally, quantitative information regarding speech rhythm can be attained by computing four different measures: the normalized pairwise variability index for vocalic intervals (nPVI-V), VarcoV, %V, and standard deviation. nPVI-V is obtained by calculating the overall mean of the differences between successive pairs of vocalic intervals divided by their sum and multiplied by 100, and VarcoV is obtained by calculating the standard deviation of vocalic interval duration divided by mean vocalic duration and multiple by 100. %V is obtained by calculating the percentage of utterance duration composed of vocalic intervals, and standard deviation is obtained by calculating the standard deviation of vocalic interval duration (Lowit and Kent, 2011).

Various studies have described and compared the acoustic parameters of speech, such as f0, intensity, rhythm, and rate of speech, in typically developing speakers and speakers with ASD. As previously mentioned, Nadig and Shaw (2012) obtained perceptual ratings of pitch, pitch changes, rate, and overall rating in 15 children with HFA and 13 typically developing children using a perceptual rating scale. In addition, they conducted an acoustic analysis to obtain acoustic measurements of mean f0, f0 range, and conversational rate of speech in the same 15 children with HFA and 13 typically developing children described in the perceptual component of the study. A conversational speech sample was elicited from each participant preceding an analysis of the speech sample. Praat software was used to obtain the mean f0, maximum and minimum f0, and duration of the speech samples. The f0 range and rate of speech were also obtained. F0 range was calculated by subtracting the minimum f0 from the maximum f0, and the rate of speech was calculated by counting each syllable, dividing the number of syllables by the duration of the speech sample, then multiplying the number by 60 to get the final measurements in syllables per minute. The measurements revealed that there were no significant differences in rate of speech between the two groups, and f0 range was significantly lower in the typically developing group than in the HFA group. There were no correlations between individual differences in f0 range and specific participant characteristics, such as IQ, language level, and ASD severity in either of the two groups. The authors conclude that the elevated f0 range seen in the HFA group provides evidence for variable intonation as a prosodic characteristic of individuals with HFA.

Previous findings regarding comparisons of mean f0 in individuals with ASD and typically developing individuals are variable with some researchers reporting no significant differences and others reporting both significantly higher and significantly lower mean f0 in individuals with ASD. Nadig and Shaw's (2012) finding that there were no significant differences in mean f0 or speech rate show that elevated mean f0 and may not be a consistent prosodic feature in individuals with ASD but may instead be dependent upon each individual case. Further research is needed to explore the differences in mean f0 seen amongst speakers with ASD.

In addition to analyses of conversational speech samples, Nadig and Shaw (2012) also conducted an acoustic analysis of speech from structured communication tasks where mean f0, f0 range, and rate of speech were measured from isolated, one-utterance verbal productions. Comparably to the conversational speech acoustic analysis, mean f0 range was lower in the typically developing group than the HFA group, and there were no significant differences in mean f0 or rate of speech. While in the conversational speech acoustic analysis there were no correlations between individual differences in f0 range and specific participant characteristics, such as IQ, language level, and ASD severity, f0 range showed a negative correlation with IQ in the HFA group in the structured communication task acoustic analysis. HFA individuals with lower IQs exhibited higher f0 range; however, there were no correlations between f0 range and language level or ASD severity in the HFA group. In response to the correlation between IQ and f0 range in the structured speech task and not conversational speech, the authors presume that "prosodic modulation is more related to general cognitive abilities when encoding information in a constrained task where an object needs to be described, as opposed to open-ended conversation." These findings suggest that f0 variation is a consistent prosodic feature in individuals with HFA across multiple communicative situations, contradicting the stereotype of monotone intonation in speakers with ASD. The findings also suggest that speech rate and mean f0 vary among speakers with ASD and should be examined on an individual basis when determining a prosodic intervention plan.

Having a distinct understanding of the acoustic features of children with ASD is not only helpful for generating a specific intervention plan to target prosodic deficits, but it may also assist researchers and clinicians in identifying individuals with ASD based on the presence of specific prosodic deficits. Specifically, using acoustic analyses to identify infants with ASD based on their verbal productions may assist professionals in the early detection of ASD to subsequently allow for early intervention. Brisson, Martel, Serres, Sirois, and Adrien (2014) conducted a study to assess the prosodic differences in the vocal productions of typically developing infants and infants later diagnosed with ASD with the postulation that infants later diagnosed with ASD would produce more monotone verbal productions than typically developing infants. The researchers analyzed the family home-videotapes of 13 infants later diagnosed with ASD and 13 typically developing infants. The participants in each videotape were less than 6 months old. The duration, mean f0, and pitch contours of vocal productions were analyzed using Praat with four different pitch contour classes: simple contour, one-inflection contour, two-inflection contour, and complex contour. The simple contour class consists of rising, falling, and flat contours, and the one-inflection contour class consists of rising-falling and falling-rising contours. The two-inflection contour class consists of rising-falling-rising and falling-rising-falling contours, and the complex contour class consists of contours with more than two inflections, such as rising-falling-rising-falling. There were no significant differences in duration or mean f0 between the two groups; however, the infants later diagnosed with ASD produced significantly fewer complex pitch contours and significantly more simple pitch contours than the typically developing infants.

The duration, mean f0, and pitch contours of the infants' mothers' vocal productions were also analyzed to examine how infants' responsiveness impacts their mothers' behaviors. There were no significant differences in pitch contour or mean f0 between the two groups; however, mothers of infants later diagnosed with ASD produced utterances with overall shorter durations than the mothers of typically developing infants. This may be due to the concept of positive reinforcement, that is, the mothers may be less motivated to produce lengthy utterances due to the lack of infant feedback (Brisson, Martel, Serres, Sirois, & Adrien, 2014)

The results of the study conducted by Brisson et al. (2014) suggest that infants who are later diagnosed with ASD tend to exhibit prosodic differences before 6 months of age; specifically, they produce more monotonous vocalizations than typically developing infants based on their decreased production of complex pitch contours and increased production of simple pitch contours. Analyzing the acoustic parameters of infants, specifically pitch contours, may allow clinicians and other professionals to identify those with ASD at an earlier age to subsequently begin intervention at an earlier age. This information may also be useful for educating parents on the importance of increased utterance length and duration to provide more input to their infants since infants are reactive to linguistic input from birth and imitation and positive reinforcement affect language learning in a positive way.

The outcomes of Brisson et al. (2014) and Nadig and Shaw (2012) provide conflicting information regarding f0 variation. Brisson et al. (2014) found that infants who are later diagnosed with ASD tend to produce more monotonous vocalizations than typically developing infants based on their decreased production of complex pitch contours, while Nadig and Shaw (2012) found variation in f0 to be a consistent prosodic feature in individuals with HFA across multiple communicative situations. Nakai, Takashima, Takiguchi, and Takada (2014) describe a feasible explanation of the variation of monotonous speech in individuals with ASD. The goal of their study was to first describe the differences in intonation between children with ASD and typically developing children using acoustic analysis, then to examine how variations in fundamental frequency patterns, or pitch variation, change from preschool age to school age in both children with ASD and typically developing children. Additionally, they examined the relationship between variations in fundamental frequency patterns and degree of ASD symptoms.

The participants in the study described by Nakai et al. (2014) were split into four groups: an ASD preschool age group, an ASD school age group, a typically developing preschool age group, and a typically developing school age group. All participants were administered a picture card naming test, and all responses were recorded and analyzed to evaluate variations in fundamental frequency patterns. The parents of each participant completed the Autism Screening Questionnaire (ASQ) to assess three domains: social reciprocal interaction, communication, and repetitive behavior and stereotyped patterns. The results showed a relationship between variation in fundamental frequency patterns and age. There was no significant difference between variation in fundamental frequency patterns in ASD children and typically developing children at preschool age; however, the typically developing children showed a significantly greater pitch variation than the ASD children at school age. Additionally, the school age typically developing group showed significantly greater pitch variation than the preschool aged typically developing group, while there was no significant difference in pitch variation between the preschool aged ASD group and the school aged ASD group. This could be a result of typically developing children gradually developing expressive prosodic abilities after they reach school age while children with ASD maintain monotonous speech after reaching school age. The results also showed a relationship between pitch variation and degree of one ASD symptom. While there was no significant relationship between pitch variation and communication or repetitive behavior and stereotyped patterns, there was a negative correlation between pitch variation and social reciprocal interaction. This negative correlation between pitch variation and social reciprocal interaction may be due to a relationship between prosody and empathy, or responsiveness, in individuals with ASD.

Although the results of the studies conducted by Brisson et al. (2014), Nadig and Shaw (2012), and Nakai et al. (2014) show conflicting results, this may be explained by one factor. The participants used in the study described by Nadig and Shaw (2012) had a diagnosis of HFA while the participants in the studies by Brisson et al. (2014) and Nakai et al. (2014) each had a diagnosis of ASD. This indicates that there may be in fact a relationship between prosodic skills and autism severity, and speakers on the upper end of the autism spectrum may have more advanced prosodic skills than speakers who are lower on the autism spectrum. As indicated by the conclusions of Nakai et al. (2014), a negative correlation between pitch variation and social reciprocal interaction may be due to a relationship between prosody and empathy, or responsiveness, in individuals with ASD. This explains why speakers with HFA with more sophisticated social reciprocal skills also have more sophisticated prosodic skills. If this idea is true, then approaches to prosodic intervention for individuals with ASD will vary based on each individual client's specific deficits and their autism severity. Conducting acoustic analyses would be an efficient way to identify each individual client's specific prosodic deficits to guide intervention.

Hartzheim and Kim (2017) also compared the speech rate and frequency in typically developing (TD) speakers and speakers with ASD. They analyzed speech samples obtained from TD children between the ages of 9 and 14 as well as children with ASD matched for age and gender. Contrarily from the results of the study by Nadig and Shaw (2012) reporting no significant differences in rate of speech, Hartzheim and Kim (2017) found that speech rate was greater in the children with ASD than the TD children. However, these results correlate with study described by Nadig and Shaw (2012) in which perceptual ratings were obtained for rate of speech, and the ASD group received higher rate of speech scores than the TD group. Oppositely from the results explained by Nakai et al. (2014), Hartzheim and Kim (2017) found that mean frequency and frequency range were both higher for the ASD group than the TD group. They also found no significant differences in frequency standard deviation between the two groups. These findings coincide with the suggestion by Nadig and Shaw (2012) that speech rate and mean f0 vary among speakers with ASD and should be examined on an individual basis when determining a prosodic intervention plan.

Hartzheim and Kim (2017) also compared speech rhythm in typically developing speakers and speakers with ASD. In addition to speech rhythm, they analyzed intensity ranges within the speakers. Following an analysis of speech samples, they found the speakers with ASD produced an overall decreased intensity range in comparison to the TD speakers as well as a higher intensity standard deviation. They used four measures to analyze speech rhythm: Normalized pairwise variability index for vocalic intervals (nPVI-V), standard deviation, VarcoV, and %V. They reported that the ASD speakers "exhibited reduced durational variations among vocalic nuclei measured by the four rhythmic parameters" (Hartzheim & Kim, 2017) in comparison to the TD speakers. The ASD speakers produced speech with a lower nPVI-V and speech rhythm standard deviation and a higher %V than the TD speakers. There was significant difference in VarcoV between the two groups. Since the literature discussed thus far provides some conflicting information regarding acoustic parameters in speakers with ASD and typically developing speakers, more research may be warranted to obtain objective measures of the specific prosodic characteristics within the ASD population.

Importance of Prosody and Acoustic Analysis of Prosodic Parameters

Diehl and Paul (2013) describe several functions of prosody in speech, such as structuring speech, clarifying syntactic structure, and communicating emotion. Prosodic patterns also allow speech to sound monotone or overstressed as well as fast or slow (Diehl & Paul, 2013). These features combine in a unique way to give each speaker's speech typicality yet a unique character. Obtaining information regarding the prosodic features of individuals with ASD provides clinically valuable information because deficits in prosody, such as the ability to vary pitch, loudness, and rhythm appropriately, create a communication barrier and make it difficult for speakers to efficiently express their emotions and messages. It also makes it difficult for listeners to comprehend messages appropriately. This communication barrier may, in turn, create a social barrier due to the inability to properly communicate intended meanings with others. Since deficits in prosody are not frequently addressed by clinicians when treating children with ASD, these children may be experiencing negative social experiences as a result of deficits in pragmatics due to receptive and expressive prosody difficulties that go untreated.

Aiming to find a relationship between prosodic and pragmatic abilities in children with ASD, Peppé, McCann, Gibbon, O'Hare, and Rutherford (2006) conclude from their case study of a 7-year-old child with ASD that specific prosodic deficits can affect pragmatic ability. The child described in the case study, Adam, was administered all subtests of the PEPS-C, and his scores were compared to typically developing children and children with HFA matched for verbal mental age. Adam's PEPS-C and prosodic tendencies were parallel to those mentioned in the literature describing individuals with ASD. He scored slightly higher on the tasks that consisted of longer items, such as the prosody form tasks, focus, and chunking than on the tasks that consisted of shorter items, such as the intonation form tasks, affect, and turn-end. He displayed deficits in stress placement and auditory discrimination, and his imitation skills were inconsistent. This shows that Adam had difficulties with both expressive and receptive prosody. Adam was also administered The Children's Communication Checklist (CCC) to assess his communication and pragmatic skills. A composite score lower than 132 is indicative of an impairment, and Adam obtained a score of 98 demonstrating difficulty with conversational pragmatic ability. Specifically, Adam's utterances seemed illogical, and he demonstrated an inability to understand sarcasm and true message meanings, interpret tones of voice, and communicate clearly. The authors suggest that Adam's utterances appeared illogical as a result of stressing words inappropriately in utterances due to difficulties with expressive prosody as determined by the PEPS-C. They also suggest that his difficulties with understanding sarcasm and true message meanings, interpreting tones of voice, and communicating clearly are a result of his difficulties with receptive prosody that were also demonstrated by his PEPS-C scores. This apparent relationship between prosody and pragmatics suggests that discovering an efficient method to identify the specific prosodic deficits in each child with ASD, such as an acoustic analysis of prosodic features, will provide clinicians with a specific prosodic target for intervention that will consequently improve pragmatic skills.

Summary

While some researchers and clinicians rely on perceptual evaluation of prosody, perceptual ratings and measurements are typically subjective and prone to inconsistencies. Also, research shows that listeners may not be able to fully interpret atypical prosody perceptually; therefore, using an acoustic analysis is a more efficient way to describe the exact differences in prosodic features of different groups of speakers. Analyzing the acoustic features of atypical expressive prosody in speakers with ASD would also provide more detailed and defined information regarding the nature of the prosodic abnormality in these individuals to guide clinicians in providing a more concentrated focus for intervention.

Knowledge regarding the acoustic parameters in speakers with ASD is significant information for clinicians since research shows that there is a relationship between prosodic skills and pragmatic deficits as well as autism severity. Since prosodic deficits can affect pragmatic ability, discovering an efficient method to identify the specific prosodic deficits in each child with ASD, such as an acoustic analysis of prosodic features, can provide clinicians with a specific prosodic target for intervention that will consequently improve pragmatic skills and reduce the social difficulties that are often seen within the ASD population. The presence of a relationship between prosodic skills and autism severity tells us that approaches to prosodic intervention for individuals with ASD should vary based on each individual client’s specific prosodic deficits influenced by their autism severity.

Research Question

The purpose of the current study was to compare the acoustic parameters of children between the ages of three and six with ASD to age matched typically developing speakers. Obtaining this information will provide researchers and clinicians with the information needed to identify prosodic deficits. The following question guided the study.

(1) What are the differences between the acoustic parameters of prosody (f0, intensity, speech rate, speech rhythm) in speakers with ASD and typically developing speakers between the ages of three and six?

Based on the previous findings discussed thus far, we hypothesized that children with ASD would exhibit significant differences in the following acoustic parameters of prosody:

(1) *Fundamental frequency*. Children with ASD will exhibit higher mean f0 and f0 range than typically developing children.

(2) *Intensity*. Children with ASD will exhibit a greater intensity range than typically developing children.

(3) *Speech rate*. Children with ASD will exhibit a higher articulation rate than typically developing children.

(4) *Speech rhythm*. Children with ASD will exhibit reduced durational variations between vocalic nuclei in comparison to typically developing children.

CHAPTER 2.
METHODS

Participants

Data included speech samples taken from five English-speaking, monolingual children with a formal diagnosis of ASD per parent report as well as five typically developing (TD) children matched for age and gender. Participants' ages range from 4 to 6 years. ASD participants were recruited from The Emerge Center, a facility in the southeastern region of Louisiana dedicated to providing services to children with ASD, as well as the neighboring public-school system. Control participants were also recruited from the neighboring public-school system. Children with hearing impairments and other developmental disorders as well as multi-lingual children were excluded from the study. Participants unable to produce utterances containing at least three syllables were excluded. Table 1 provides a summary of participant demographics.

Table 1. Participant demographics

	ASD Group	Control Group
Total Participants	5	5
Average age	72 months (range: 56-83 mo.)	68 months (range: 48-81 mo.)
Gender		
# of males	2	2
# of females	3	3
Ethnicity		
Caucasian	3	5
African American	1	0
Asian	1	0

Procedure

IRB approval was attained prior to commencement of the study, and parental consent was obtained prior to participation in the study. Speech samples were collected during structured play with picture books and toys used as stimuli to elicit speech. During play, prompts were provided by the examiner to facilitate conversation. Speech sample collection took place in a small, quiet room at the child's school or home over one 30-minute session. Sessions were video recorded using an iPad on a tripod capturing the entire room for later review and analysis. Speech samples were analyzed by a Communication Sciences and Disorder university graduate student, the author of this paper, trained by a researcher with a Ph.D. in Communicative Disorders specializing in speech acoustics. TF32 (Milenkovic, 2005) was used to analyze the speech samples for f0, intensity, speech rate, and speech rhythm. A nonparametric analysis, the Mann-Whitney U test, was used to determine significance between the two groups at an alpha level of 0.05. A nonparametric statistic test was used due to a non-normal distribution. Equal variances were not assumed.

Data Analysis

Audacity software was used to extract the audio from each video file and separate every speech sample into 30 breath groups, each containing at least three syllables. A breath group was defined as an utterance produced in a single exhalation. Speech samples were analyzed for f0, intensity, speech rate, and speech rhythm.

Pitch, or fundamental frequency (f0), was analyzed for mean f0, f0 range, and standard deviation using TF32. The mean f0 measure was obtained by calculating the average f0 value within each utterance, and the f0 range was obtained by calculating the difference between the maximum and minimum f0. The f0 standard deviation was obtained by calculating the standard deviation from f0 distributions across each utterance.

Intensity was analyzed for intensity range and standard deviation. The intensity range was obtained by calculating the difference between the maximum and minimum intensity within each breath group, and the intensity standard deviation was obtained by calculating the standard deviation from intensity distributions across each utterance.

Speech rate was analyzed for speech rate, which was obtained by calculating the number of syllables produced per second. Finally, speech rhythm was analyzed for four different measures: the normalized pairwise variability index for vocalic intervals (nPVI-V), VarcoV, %V, and standard deviation. nPVI-V was obtained by calculating the overall mean of the differences between successive pairs of vocalic intervals divided by their sum and multiplied by 100, and VarcoV was obtained by calculating the standard deviation of vocalic interval duration divided by the mean vocalic duration and multiply by 100. %V was obtained by calculating the percentage of utterance duration composed of vocalic intervals, and standard deviation was obtained by calculating the standard deviation of vocalic interval duration. Table 2 provides a summary of the acoustic variables included in the analysis (Lowit and Kent, 2011).

Table 2. Acoustic variables included in the analysis

Aspect	Measure	Description
F0	Mean (Hz)	Average F0 value within each utterance
	Range (Hz)	Difference between maximum F0 and minimum F0
	Standard Deviation (Hz)	Standard deviation from F0 distributions across each utterance
Intensity	Range (dB)	Difference between maximum intensity and minimum intensity
	Standard Deviation (dB)	Standard deviation from intensity distributions across each utterance
Speech rhythm	Normalized Pairwise Variability Index for Vocalic Intervals (nPVI-V)	Overall mean of the differences between successive pairs of vocalic intervals divided by their sum and multiplied by 100
	VarcoV	Standard deviation of vocalic interval divided by mean vocalic duration multiplied by 100

(Table Cont'd.)

Aspect	Measure	Description
Speech rhythm	%V	Percentage of utterance duration composed of vocalic intervals
	Standard Deviation (ms)	Standard deviation of vocalic interval duration
Speech rate	Articulation Rate (syl/sec)	Number of syllables per second

(Table Cont’d.)

CHAPTER 3.
RESULTS

Differences in Speech Rate

A Mann-Whitney U test indicated that there was no significant difference in speech rate between the ASD group (M = 3.48) and the TD group (M = 4.20) (Figure 1).

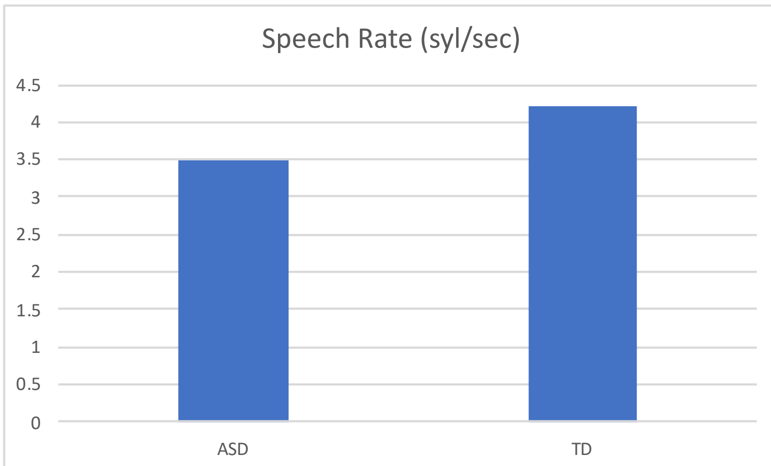

Figure 1. Speech rate group averages

Differences in Speech Rhythm

A Mann-Whitney U test indicated that there was no significant difference in nPVI-V between the ASD group (M = 51.21) and the TD group (M = 47.34). There was also no significant difference in standard deviation between the ASD group (M = 42.99) and the TD group (M = 45.39), and there was no significant difference in VarcoV between the ASD group (M = 39.16) and the TD group (M = 41.81). However, a Mann-Whitney U test indicated that %V was significantly greater for the TD group (M = 53.95) than the ASD group (M = 37.84), p = 0.028 (Figure 2).

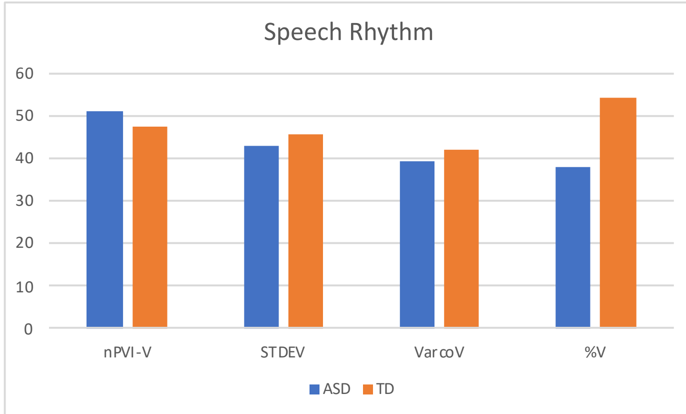

Figure 2. Speech rhythm group averages

Differences in Fundamental Frequency

A Mann-Whitney U test indicated that there was no significant difference in frequency range between the ASD group (M = 313.96) and the TD group (M = 352.69). However, a Mann-Whitney U test indicated that the frequency mean was significantly greater for the TD (M = 298.17) group than the ASD group (M = 203.98), p = 0.009. A Mann-Whitney U test also indicated that frequency standard deviation was significantly greater for the ASD group (M = 83.86) than the TD group (M = 64.33), p = 0.047 (Figure 3).

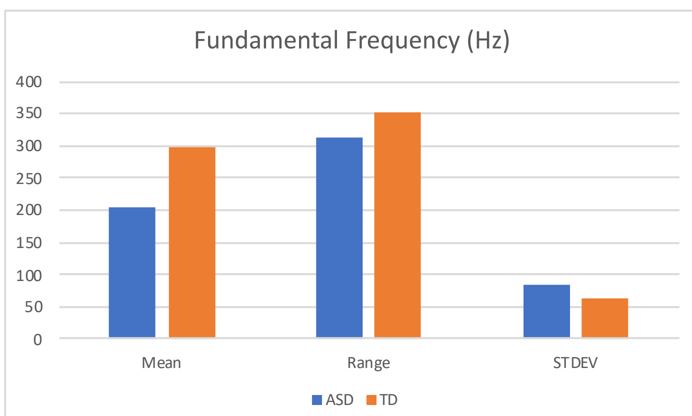

Figure 3. Fundamental frequency group averages

Differences in Intensity

A Mann-Whitney U test indicated that the intensity range was significantly greater for the TD group (M = 27.50) than the ASD group (M = 20.66), p = 0.016. A Mann-Whitney U test also indicated that intensity standard deviation was significantly greater for the TD group (M = 6.51) than the ASD group (M = 4.62), p = 0.009 (Figure 4). A summary of results is reported in Table 3.

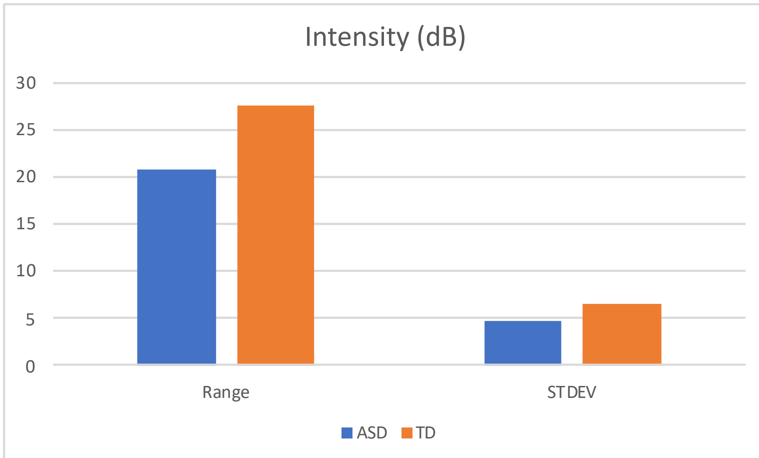

Figure 4. Intensity group averages

Table 3. Results of comparison between ASD and TD for each acoustic variable

Aspect	Measure	Group Comparison (Mean)			p-value
		ASD		TD	
Speech rate	Articulation Rate (syl/sec)	3.48	<	4.20	NS
Speech rhythm	Normalized Pairwise Variability Index(nPVI-V)	51.21	>	47.34	NS
	Standard Deviation (ms)	42.99	<	45.39	NS
	Varco V	39.16	<	41.81	NS
	%V	37.84%	<	53.95%	0.028
F0	Mean (Hz)	203.98	<	298.17	0.009
	Range (Hz)	313.96	<	352.69	NS
	Standard Deviation (Hz)	83.86	>	64.33	0.047
Intensity	Range (dB)	20.66	<	27.50	0.016
	Standard Deviation (dB)	4.62	<	6.51	0.009

CHAPTER 4.
DISCUSSION

Findings as Related to Previous Studies

Consistent with previous research by Nadig and Shaw (2012), there is no significant difference in rate of speech between speakers with ASD and TD speakers both at the preschool age and at school age. However, Hartzheim and Kim (2017) found that speakers between the ages of 9 and 14 with ASD produce a higher rate of speech than TD speakers. It may be possible that speech rate remains consistent between preschool age and school age and changes to an increasing rate between school age and pre-adolescent to adolescent years. A change in speech rate occurring at this specific point in time may be a result of negative experiences in social situations that build up anxious behavior over time.

With respect to speech rhythm, we found no significant difference in nPVI-V between the two groups of preschool age children, while previous research by Hartzheim & Kim (2017) found a lower nPVI-V for ASD speakers than TD speakers between the ages of 9 and 14. Also, we found no significant difference in speech rhythm standard deviation between the two groups of preschool age children, while previous research found a lower standard deviation for ASD speakers than TD speakers between the ages of 9 and 14. We also found that preschool speakers with ASD produce a lower %V than TD speakers, while previous research with children between the ages of 9 and 14 found that speakers with ASD produce a higher %V than TD speakers. Finally, there is no significant difference in VarcoV between speakers with ASD and TD speakers both at the preschool age and at the pre-adolescent to adolescent age. Overall, we found minimal to no significant differences in the speech rhythm parameters between the two groups of preschool age children, while previous research found that ASD speakers between the ages of 9 and 14 demonstrated overall reduced durational variations between vocalic nuclei as measured by the same speech rhythm parameters. This difference indicates that speech rhythm may change to reduced durational variations between vocalic nuclei as ASD children transition from preschool age to pre-adolescent to adolescent years. As described by Peppé, McCann, Gibbon, O'Hare, and Rutherford (2006) in their case study, children with ASD also demonstrate difficulties with receptive prosody. Therefore, a change in speech rhythm with increasing age may be a learned pattern resulting from of a lack of perception of differences in rhythmic patterns eventually affecting the way in which ASD speakers produce speech. More research is warranted to determine the speech rhythm patterns in school age ASD children to help pinpoint the approximate age in which these speech rhythm changes take place.

With respect to fundamental frequency, we found there were no significant differences in mean frequency between preschool age ASD and TD speakers, which is consistent with previous research by Nadig and Shaw (2012), who conducted similar research with school age children, and Brisson, Martel, Serres, Sirois, and Adrien (2014), who assessed the prosodic differences in the vocal productions of typically developing infants and infants later diagnosed with ASD. However, Hartzheim and Kim (2017) found that mean frequency was higher for the ASD group than the TD group in pre-adolescent to adolescent children. As with the other parameters, it is possible that mean f0 changes with increasing age, specifically, between the school age years and pre-adolescent to adolescent years. This may be because f0 is lowered by higher levels of testosterone and lower levels of cortisol (Evans, Neave, Wakelin, & Hamilton, 2008). Cortisol inhibits the effects of testosterone and cortisol levels rise in response to distress and illness (Sapolsky, 1990). People with ASD tend to have a lot of anxiety and distress resulting from negative experiences in social situations, especially as they enter their adolescent years. Therefore, their voices may not deepen as much as their peers. Similarly to Nakai, Takashima, Takiguchi, and Takada (2014), we found no significant difference in frequency range between the two groups in preschool age children. However, Nakai, Takashima, Takiguchi, and Takada

(2014) found that, as children transition from preschool to school age, TD children begin to produce significantly greater pitch variations than ASD children. Contrarily, other research, such research conducted by Hartzheim and Kim (2017), shows higher frequency ranges in ASD school aged speakers than their TD peers. Therefore, it is possible that frequency range changes between preschool age and school age; however, the way it which it changes may vary, with some ASD speakers producing higher f0 ranges and others producing lower f0 ranges compared to their TD peers. This could also be explained by the evidence revealed by Nakai, Takashima, Takiguchi, and Takada (2014) that there is a relationship between pitch variation and degree of ASD symptoms, with a negative correlation between pitch variation and social reciprocal interaction. Therefore, these conflicting results could be a result of a variation in ASD severity between the participants included in the studies. Future research should measure frequency range in ASD and TD children at the preschool age, school age, and adolescent years while taking ASD severity into consideration. We also found that ASD preschool aged children produce a higher frequency standard deviation than their TD peers, while former research by Hartzheim and Kim (2017) has shown no significant difference in frequency standard deviation between ASD and TD children between the ages of 9 and 14. Therefore, it is possible that preschool age children with ASD have more pitch variability than their TD peers, while pre-adolescent to adolescent age children do not. It is possible that, as children progress through their school years, they begin utilizing a significant portion of their cognitive function to understanding content instead of how speech is produced. Consequently, as content becomes more complex, attention to and perception of pitch variability may decrease.

Intensity range is lower for speakers with ASD than TD speakers at preschool age; however, Hartzheim and Kim (2017) found that intensity range is higher for speakers with ASD than TD speakers in the adolescent years. Additionally, we found that intensity standard deviation is lower in preschool age children with ASD than their TD peers, while research with pre-adolescent to adolescent children by Hartzheim and Kim (2017) found that intensity standard deviation is higher in speakers with ASD than TD speakers. Therefore, it is possible that intensity changes between preschool age and adolescent years. Specifically, intensity variability increases during these years. This is likely because, throughout the course of the beginning of their lives, the ASD children may have received more reinforcement for a change in their intensity level. The louder they speak, the more attention and positive reinforcement they receive. Therefore, this behavior may be inadvertently reinforced by the environment causing them to be more variable in their intensity over the years. More research is warranted to determine intensity averages in school age ASD children to help pinpoint the approximate age in which these intensity changes takes place.

Clinical Implications

As mentioned in the literature review portion of this paper, prosody serves several functions in speech, such as structuring speech, clarifying syntactic structure, communicating emotion, and allowing speech to sound monotone or overstressed as well as fast or slow. These features combine in a unique way to give each speaker's speech typicality yet a unique character. Obtaining information regarding the prosodic features of individuals with ASD can provide clinically valuable information since deficits in prosody, such as the ability to vary pitch, loudness, and rhythm appropriately, can create a communication barrier and make it difficult for speakers to efficiently express their emotions and messages. It can also make it difficult for listeners to comprehend messages appropriately. This communication barrier may, in turn, create a social barrier due to the inability to properly communicate intended meanings with others. Since deficits in prosody are not frequently addressed by clinicians when treating children with ASD, these children may be experiencing negative social experiences as a result of deficits in pragmatics due to prosody difficulties that go untreated. Not only is it clinically valuable to have information regarding the prosodic features typically seen in ASD speakers, but it is also important to know how these features may change over time as children age. The current results obtained in this study along with previous research results provide some important information regarding prosodic changes in speakers with ASD between preschool age and adolescent age.

We determined that it may be possible that speech rate remains consistent between preschool age and school age in speakers with ASD and changes to an increasing rate between school age and pre-adolescent to adolescent years. This indicates that speech rate is a feature of speech that may not need to be addressed until speakers with ASD progress through their school age years.

We also determined that speech rhythm may change to reduced durational variations between vocalic nuclei as ASD children transition from preschool age to pre-adolescent/adolescent years. It was also concluded that intensity changes between preschool age and pre-adolescent/adolescent years. More research is warranted to determine the intensity and speech rhythm patterns in school age ASD children to help pinpoint the approximate age in which these changes take place so that clinician can have a better idea of when to assess children with ASD for speech rhythm and intensity abnormalities and begin intervention.

In regard to fundamental frequency, we determined the way in which frequency range changes between preschool age and school age may vary, with some ASD speakers producing higher f0 ranges and others producing lower f0 ranges compared to their TD peers. This is likely due to the idea that there is a relationship between pitch variation and degree of ASD symptoms, with a negative correlation between pitch variation and social reciprocal interaction. Clinicians should keep in mind that ASD children with more severe symptoms may present with more severe pitch abnormalities that should not go untreated.

It is vital that clinicians are aware of the possible prosodic deficits in young patients with ASD as well as the ages in which these deficits tend to appear so that intervention can begin at the appropriate age for each child and potential social barriers can be minimized or prevented.

Limitations

There are several limitations regarding the current study. First, the sample size was small, so results should be interpreted with caution. A larger sample size would provide more accurate mean values and minimize the effects of potentials outliers that could skew the data. Second, autism severity was not taken into consideration in regard to the speech parameters. Autism severity may play an important role in the speech that is produced by the children under investigation. Further limitations include the recordings taking place outside of an audio booth, so that no comparison of intensity could take place between the ASD and the TD group. All children in this study had to have sufficient verbal skills to complete the task and produce sufficient breath groups. However, some children repeated the utterances that were produced by the researcher collecting the data. Echolalia is a common phenomenon in children with ASD. The echolalic phrases may have had prosodic parameters mirroring the clinician. Analyzing echolalic speech may yield different results.

Future Directions

Future studies comparing prosodic features in speakers with ASD with TD speakers should examine children ranging from preschool age to adolescent age to determine approximately what age each prosodic feature changes. Future studies should also examine ASD speakers of varying severities to determine how ASD severity correlates with the ages in which prosodic features change. Further, separating echolalic and spontaneous speech may be beneficial in further understanding speech that is produced by a child with ASD. Additionally, once patterns of speech are identified, treatment protocols should be developed to address specific deficits.

Conclusion

In conclusion, the current study found that, of the ten variables analyzed, five of them are significantly different between ASD and TD speakers between the ages of four and six: %V, mean f0, f0 standard deviation, intensity range, and intensity standard deviation. Specifically, TD speakers have a higher %V, f0 mean, intensity range, and intensity standard deviation, while ASD speakers have a higher f0 standard deviation. Given the results of the current study in relation to previous, similar research, it appears that prosodic features change with increasing age. Therefore, it is essential that clinicians are aware of the approximate ages in which prosodic deficits tend to appear so that intervention can begin at the appropriate age for each child and potential social barriers can be minimized or prevented.

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