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Analysis of aberrant vocalization and its causes as potential early detection indicators for children with autism

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Abstract

Early detection and early management of children with Autism Spectrum Disorder (ASD) are crucial to their developmental outcomes. Vocalization refers to the noises that children create before they begin to talk. Studies have indicated that non-speech-like and speech-like vocalizations are the most prevalent cause of ASD children before the age of 2 possible identifying markers. Theoretical reasons for aberrant vocalization in children with ASD largely comprise motivation-oriented, neuromotor-oriented, sensory-oriented and social feedback-oriented to the theory. Future research may be explored to study the potential of aberrant vocalization as a unique early identification flag in children with ASD, boosting sobbing in children with ASD. Research on early screening, examining automatically trained classification models based on the best-predicted set of auditory characteristics, exploring the impact of intrinsic and social motivation on ASD The effect of children's speech-like vocalization and further research on the brain mechanism of ASD children's speech-like speech abnormalities. Thus, early detection and early action gives a more objective theoretical grounding.

Keywords: autism spectrum disorder, potential early identification markers, abnormal vocalization, cause analysis
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1 Introduction

It is a neurodevelopmental disorder with two core symptoms: first, persistent deficits in social communication and social interaction; second, restricted and repetitive patterns of behavior or interests or activities. Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder that has two core symptoms: first, persistent deficits in social communication and social interaction; and second, repetitive and restricted patterns of behavior or interests or activities [4]. There are two basic modes of onset of ASD: early onset, which occurs before the age of one year, and regressive onset, which occurs around the age of two years (regressive onset) [10]. Approximately 30% of ASDs are regressive in nature, with regression or loss of previously learned language or social abilities being the most common symptoms [90]. According to the most recent data, the global incidence of autism spectrum disorder (ASD) is just under 1 percent [66], the incidence of ASD in my country is 1/142 [103], and the incidence of ASD in the United States is 1/54 [67], indicating that the incidence of ASD is higher. Despite the fact that there is presently no particular medication for the main symptoms of ASD [44], Although timely detection and intervention in the early stage, particularly before the age

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of 2, can effectively improve the developmental trajectory of language, social communication and other abilities of individuals with ASD and influence Long-term outcomes [38, 41, 86, 97], even "prevention" of comprehensive syndromes appeared to be possible. Sigafoos and Waddington [102]. Children's vocalizations are the noises that they create before they learn to talk in their native language [82]. Nonspeech-like vocalizations and speech-like vocalizations are examples of nonclass vocalizations [71]. Non-speech-like vocalizations are vocalizations that are related with biological processes, such as fixed signals and vegetative noises, and are distinct from normal speech.

Speech-like vocalizations are speech-like sounds that contain diverse kinds and evolve along a continuum, becoming increasingly like-minded around the age of one speech [43, 70, 71]. When studying the vocalization characteristics of children with ASD, more specific indicators are typically used. For example, the frequency, proportion, fundamental frequency, pause length, duration, and other characteristics of non-speech-like vocalizations are commonly used (e.g., [33, 77]), and classifiers are used to categorize the vocalizations. Vocalization complexity and communicative vocalization are two of the most often utilized indices of speech vocalization in analytic studies (e.g., [68, 100], Table 1 lists the most prevalent forms of vocalizations as well as the most widely employed analytical indicators. Early normal development is characterized by the emergence of vocalization as a major milestone. The vocalizations of children in normal development (TD) vary from 0 to 1 in pitch. Between the ages of two and three, the amount of weeping and quasi-resonant vowels steadily reduced, while the number of vowels and canonical syllables gradually grew [21, 70]. Atypical development of vocalization is a sign of developmental abnormalities, and a greater knowledge of early vocalization may aid in the discovery and identification of neurodevelopmental disorders at an earlier stage in their growth and progression [60]. It has been shown in studies that children with autism spectrum disorder (ASD) exhibit aberrant vocalizations that are connected to their fundamental atypical communication symptoms.It has been suggested that early detection of aberrant vocalizations may be advantageous to improving the existing scenario in which children with ASD are not identified until they are between the ages of 3 and 5 years [94]. Existing research on the vocalization features of ASD, on the other hand, is contradictory. There are studies, for example, that show These findings confirm the conclusion that children with ASD make more non-verbal impatience sounds than children without ASD [77], while other research has shown the absence of a difference in non-verbal depression sounds between the two groups of children [77]. [82]. There has been research to suggest that children with ASD are more speech-like than children with TD Fewer vocalizations [75], but other research has revealed that children with ASD have excessive vocalizations [75]. So, what are the atypical vocal anomalies that occur in children with autism spectrum disorder? The likelihood that these voice anomalies will serve as early identifying indicators is uncertain. It is the purpose of this paper to summarize recent research findings on early vocalization in children with ASD, to describe the characteristics of abnormal vocalization in children with ASD, and to consider whether abnormal vocalization in children with ASD could serve as an early identification marker.The purpose of this study is to investigate the reasons of aberrant vocalization in children with ASD in order to provide some novel ideas for the early identification and intervention of children with ASD.

2 Abnormal vocalization and early identification of ASD

2.1 Non-verbal dysphonia and early recognition of ASD

Non-verbal vocalization features of children with autism spectrum disorder (ASD) are being investigated in two areas: In the first place, the frequency or percentage of non-speech utterances is measured. Second, the basic frequency, the length of the pause, and the duration of the cry are all measured

Table 1: Types, definitions and common analysis indicators of vocalization

	Types of	definition	Common analysis indicators
non-similar language speech	pleasant sound (pleasure/delight)	Sounds that express pleasant emotions, such as laughter	Frequency of non-speech-like vocalizations (number of non-speech-like vocalizations),Proportion (such as the proportion of non-speech speech in total vocalization), etc. Fundamental frequency (f0) is the vibration of the vocal cords per second The number of movements, reflecting the pitch of the sound pause length is the pause time between cries cry duration is the duration of the cry
	atypical vocalizations	An atypical sound consisting mainly of high-pitched screeching Cries, low-pitched roars, and high-intensity shouts	
	distress	A vocalization associated with negative emotional states, mainly including including loud cries, wailing	

quasi-speech voice	Quasi-resonant vowel (quasi vowel)	A weak, low-pitched, sometimes nasal voice Grunt, produced with throat closed, little respiratory support, sound Very short tones (usually less than 100 ms), above 2000 Hz Insufficient sub-energy, difficult to transcribe into adult vowels	Vocal complexity is speech-like Frequency/Frequency, Consistency and Diversity. non-canonical syllable frequency rate or frequency (quasi-resonant vowel, single vowel, single consonant,
	vowel	Produced with an open throat and clear formants	
	borderline syllable (marginal syllable	Also called marginal babbling, it means Slow CV sequence with long transitions between C and V time (usually greater than 250 ms)	
	canonical syllable (canonical syllable	It mainly includes a single CV syllable and canonical babbling composed of 2 or more CV sequences. Fast transitions between C and V (usually less than 250ms). Among them, canonical babbling includes overlapping babbling (with the same CV combination sequence) and non-overlapping babbling (nonreduplicated babbling, with varying different CV combination sequences)	
	complex syllable (complex syllable)	Mainly includes VC, CCV other than CV syllables Equal monosyllabic, complex disyllabic such as VCV, VCVC, VCVCV, VCVCCV, etc. with or without accent and intonation polysyllabic string	

Non-verbal vocalizations include fixed signal noises and vegetative sounds, which include reflex vocalizations as coughing, burping, and sneezing. Plant noises are seldom studied in study, thus we only included fixed signal sounds. C: consonant; V: vowel

Despite the fact that the frequency and amount of non-verbal vocalizations have been shown to vary, there has been a consistent pattern of results (e.g., [77, 82]). The acoustically aberrant properties of cry in non-speech-like vocalizations have, on the other hand, been the subject of very consistent research, with the result being that children with ASD had higher fundamental frequencies, shorter pause lengths, and shorter durations of cry (eg, [9, 30, 34]).

2.1.1 Crying with a higher fundamental frequency is a possible early identifying indication of autism spectrum disorder.

The fundamental frequency has been identified as the metric that most accurately represents the acoustic properties of cry [65]. A Study on Crying in Children with Autism Spectrum Disorder (ASD) is frequently utilized by researchers. In the research, the fundamental frequency of weeping in children with ASD was determined.The samples are mostly drawn from two categories: First, familiar or unfamiliar natural emotions that are not accompanied by pain weeping in natural conditions; second, pain crying in natural situations that are accompanied by familiar or unfamiliar natural feelings Voice. According to the findings of the research, the basic frequency of weeping in ASD children is greater than in TD children of the same age. Early sobbing in children with identified ASD was captured on film at home and analyzed.Using this method, the researchers discovered that the fundamental frequency of the non-pain scream of 5-18 month old babies with ASD is much greater [9, 32, 33, 34, 36, 37]. Infants at high risk for ASD and their ages at 15 months older ASD children between the ages of 36 and 52 months, who had increased non-unfamiliar scenario

anxiety in unfamiliar settings The basic frequency of pain scream lends confirmation to the findings presented above [37, 73]. A prospective research showed that familiar natural Situational 6-month-old ASD high-risk babies had a high fundamental frequency of painful crying, which is consistent with their familiar natural environment.There was no statistically significant difference in nonpainful crying between the two groups for low-risk babies; however, infants who were eventually identified with ASD had the highest fundamental frequencies of cry and the lowest fundamental frequencies of cry [83]. The information presented above demonstrates that higher The basic frequency of weeping may be an early identifying indication of autism spectrum disorder, particularly in boys. A high basic frequency of pain crying may be a more sensitive indication than a lower fundamental frequency.

2.1.2 Crying pauses that are shorter in length and duration are possibly early indicators of ASD.

The length and duration of a crying pause are indicative of respiratory control ability [61], which has been studied further in the research of baby crying in children with ASD [61]. It has been shown in studies that the length and duration of pauses in weeping in children with ASD are shorter than those in children with TD of the same age and developmental stage. According to research, 12- to 13-month-old ASD babies cry for much shorter periods of time than TD infants [33, 34, 35, 95]. A prospective research discovered that ASD high-risk children cried for a shorter period of time at 12 and 15 months than TD infants, and at 2 or 3 years, they cried for a shorter period of time than TD infants.Infants with ASD who were diagnosed at 2 years of age cried for the lowest amount of time [30, 93]. According to the findings shown above, a shorter cry pause length and duration may be an early distinguishing indication of autism spectrum disorder.

2.2 Speech-like dysphonia and early recognition of ASD

2.2.1 Abnormal vocalization complexity is a potential early identification of ASD logo

There have been a large number of research conducted on the vocal complexity of children with ASD. Despite the fact that two studies have revealed that children with ASD or those at high risk for ASD are more likely to be violent, Children's vocal complexity did not vary substantially from that of TD children in two studies [15, 89], however there is more evidence that TD children had higher vocal complexity. The demonstration of inappropriate speech-like vocal complexity in children with Autism Spectrum Disorder It is mostly exhibited as a difference in the complexity of speech-like vocalizations between TD children of the same age who have a lower or greater level of complexity (e.g., [43, 53**?**]. First and foremost, the majority of research have proven that children with ASD experience polyphony, which is similar to speech. The heterogeneity is lower in TD children of the same age than in non-TD youngsters. Table with data from prospective and retrospective studies Ming, vowels, marginal syllables, and normative sounds in babies with autism spectrum disorder (ASD) before the age of two. When compared to TD babies, the frequency or percentage of speech sounds such as syllables is much reduced [43, 75, 77], and the number of consonant types is significantly smaller [82, 26]. Infants at high risk for autism spectrum disorder When comparing high-risk infants to low-risk infants, vowels, standard syllables, complex syllables, and other speech sounds rate or proportion [14, 53, 76] as well as consonant types [76] were lower than when comparing high-risk infants Studies have also shown that speech-like vocal complexity is a strong predictor of autism spectrum disorder diagnosis. According to [75], canonical syllables accounted for around half of the total. The syllable-to-voice ratio was shown to be 90 percent accurate in predicting the diagnosis of autism spectrum disorder. At 9 and 12 months, [76] discovered a high risk of autism spectrum disorder (ASD). Consonant type in babies accurately predicts the onset of ASD symptoms at 24 months. The accuracy percentages are 77 percent for the first and 65 percent for the second. According to the research presented above, reduced Speech-like vocalization complexity may be an early indicator of ASD.Another point to mention is that a tiny proportion of children with Regression ASD have sophisticated speech sounds. The level of sexuality is greater than that of TD children of the same age, and there is an excessive amount of singing. retrospective According to the findings of the research, 15 12-month-old babies with regressive ASD relapsed. The frequency of babbling was greater in TD babies than in the other 21 infants with early-onset ASD, whereas the frequency of complex babbling was lower in TD infants than in the other 21 infants. further According to the findings, 46 percent of babies with regressive ASD had complicated babbling frequency. Early-onset ASD children who are above or equal to the mean for TD newborns are just 6 percent more likely to display this phenomena). In addition, the research discovered that regression increases with age.

At 24 months, complex babbling in children with autism spectrum disorder (ASD) gradually degenerates. When their complicated babbling is the same as that of babies with early-onset ASD, they are both far behind TD infants in terms of developmental milestones. A recent prospective research discovered that 9-month-old high-risk children with ASD make more speech-like vocalizations than 9-month-old low-risk infants, with this finding being mostly represented in 12 ASD high winds.

Excessive vocalization in newborns who are at risk [51]. above-mentioned conclusion The findings show that greater vocal complexity in children may be connected with regressive autism spectrum disorder (ASD).Identification markers for children at an early age.

2.2.2 Less communicative vocalization is a potential early identification of ASD logo

Communication vocalization may be used to assess the vocal society of children with autism spectrum disorder (ASD) [68]. Children with ASD flee less vocally than TD children at the same age, and this is purposeful among babies with ASD before the age of two, according to research. In comparison to TD babies, the figures in this study had much reduced verbal communication activity [5, 25, 26, 77, 85, 96]. A study of high-risk babies with ASD provides more evidence. Infants with high risk of ASD had less social engagement, which was consistent with the findings above.

Compared to low-risk infants, high-risk infants with excessive vocalization had lower social babbling than low-risk infants [43, 80, 98]. In addition, ASD high-risk infants with excessive vocalization had lower social babbling than low-risk infants [43], [51]. The information presented above implies that communicative vocalization may be a contributing factor to ASD.

Early identification of characteristics that interact with vocalization complexity may prove to be a more accurate predictor of autism spectrum disorder (ASD).

3 Analysis of the causes of abnormal vocalization in children with ASD

According to a review of available data, children with ASD cry in a non-speech-like manner with greater fundamental frequency and shorter pauses and durations; their speech sounds are quite comparable to those of their peers. Vocal complexity may be reduced or increased, and vocalizations can be more or less communicative. This These atypical vocalizations may not only be early identification markers of autism spectrum disorder (ASD), but they may also represent the social communication and social interaction of children with ASD to a certain degree. faults at the heart of the motion Action-oriented, sensory-oriented, and social feedback-oriented Theories are combined with motivation-oriented and neurological Theories in the form of the following list: There are findings that may be used for further study and interpretation.

3.1 Motivation-oriented theory

Children with autism spectrum disorder (ASD) have strong intrinsic drive for their specific hobbies.To a certain degree, this explains the unusual intricacy of their vocalizations, which are similar to speech.Intrinsic motivation is defined as an individual's spontaneous goodwill, curiosity, and interest, as well as the desire to actively exercise skills and acquire information.Supported by the dopaminergic system, this system is engaged in the regulation of attention and the participation of oneself.The neural network connection of cognition, according to the findings [24]. The important concept is to I generate and target selection, as shown by a computer modeling research [1**?**]. Infants' intrinsic drive permits them to construct their own worlds, experiment with their own vocalizations, and devise their own study programs, according to baby psychologists. Following the first self-exploration phase in which the surrounding speech environment is ignored, the vocalization phase begins.

When imitative vocalizations are impacted by adult speech, they automatically shift from non-speech-like vocalizations to indistinct quasi-elements, which are then transformed into clear canonical syllables, which is the case for infants. Infants with Down syndrome have intrinsic motivation. The importance of speech vocalization has also been shown in behavioral study, according to TD. Games of independent exploration and discovery are the most common sources of infants' speech-like vocalizations [71]. When adults desire social engagement with newborns, they are known as "social seekers." When infants are moving, the bulk of their vocalizations (about 60%) do not seem to be directed towards adults Human; when an adult is there with the child but does not seek to engage the infant The benefit of using exploratory vocalizations was greater (about 80%) than the disadvantage [71]. Individuals with autism spectrum disorder (ASD) are more likely than the general population to have more intrinsic drive to participate in specific interests stereotyped [46], and this phenomena is seen in babies with ASD before the age of two. Additionally, it is clear [5]. ASD kids may prefer to play with syllables over and over again, while TD newborns are more likely to be interested in the subtleties of phonetic variation [71]. Then it may be deduced that the ASD infant's high intrinsic desire for unique interests may have affected his development of the complexity of speech sounds, particularly the variety of consonants, and the acquisition of phonological complexity.

At the same time, it may result in regressive ASD youngsters who make vocalizations that sound like speech. The level of complexity is too high. It is important to note that there is now a scarcity of intrinsic drive. An investigation

on the impact of speech-like vocalizations in children with autism spectrum disorder (ASD). More recently, [**?**] sought to investigate the relationship between intrinsic desire and normative syllables.

Infants with various levels of ASD risk are affected by intrinsic motivation.

The formation of normative syllables in children's speech. Infants who will be diagnosed with autism spectrum disorder in the future Children's inquisitiveness may give intrinsic incentive to impact speech-like vocalizations, according to recent research.

Children with Autism Spectrum Disorder (ASD) may exhibit communicative vocalizations as a result of social motivation deficiencies. One of the most insignificant causes. It is a collection of psychological dispositions and biological processes that encourage individuals to become more integrated into society. It includes the desire to meet others, seek and achieve enjoyment via social engagement, and the desire to create, nurture, and preserve social ties [17]. In their conclusion, [17] said that, on the basis of the data now available, disruption of social motivational systems may represent a key weakness in ASD. trap. There is a deficit in social motivation and dysfunction of the social reward brain area in ASD, which is related to the caudate nucleus and anterior cingulate gyrus. There are also functional connectivity abnormalities between the ventral tegmental area and the nucleus accumbens of the midbrain in ASD [19, 88]. ASD Children pay less attention to their parents' looks and engage less in their interactions with them. Contributing to the social motivation deficit concept is the act of initiating coattentional contacts with others. [2, 47] have provided compelling evidence. Children with ASD seldom actively communicate with others in the form of speech-like vocalizations, according to the socially motivated deficiency model of the disorder. Additionally, the development of children's speech-like vocalizations requires the interaction of children and adults as two separate topics [28, 72].

Social motivation problems in children with ASD make it difficult for them to create positive social interactions with other children their age. As a result, social motivation may potentially have an impact on the development of vocal complexity in children with autism spectrum disorder. However, there is presently no research on the impact of social drive on the development of speech-like vocalization in children with autism spectrum disorder at this time. The amount of empirical study in this area is quite small, and more research in this sector will be required in the future, according to the researchers.

3.2 Neuromotor Orientation Theory

Immaturity or a disruption in the production of speech-like vocalization neuromotor The intricacy of speech sounds in children with autism spectrum disorder (ASD) may have special consequences. kind In order to understand the neuromotor process of speech vocalization, it is necessary to first understand the neuromotor features of speech. a large number of studies use meaningless vowels or canonical syllables as material for the nervous system of speech production to conduct research [57], and a large number of studies use meaningless vowels or canonical syllables as material for the nervous system of speech production to conduct research [57]. [60]. The primary motor cortex is situated in the frontal lobe. The Laryngeal Motor Cortical (Laryngeal Motor Cortical, LMC) is a part of the brain that controls the motions of the larynx [27]. Researchers have discovered that the main motor cortex laryngeal and mandibular muscle control areas overlap in the sub plasma of the right fMRI studies of vowel articulation, according to their findings. Several researchers have hypothesized that this intercortical overlap may be responsible for laryngeal vocalization as well as inferior coupling between jaw oscillations, which would result in a syllable structure [11]. In addition, the frontal cortex's cognitive function is engaged in the regulation of sound perception and production [48]. Children with ASD who are diagnosed before the age of two, on the other hand, Frontal and other cortical enlargement have been reported [8, 52, 51, 56], which may impair speech-like regulation of vocal movement, leading in varying speech-like vocal complexity often in the population. How do children with ASD now regulate their vocal organs in order to synchronize their speech? Furthermore, the neuromotor process that controls speech-like vocalizations is still not fully understood, and further study in this area is required.

Children with Autism Spectrum Disorder (ASD) may exhibit speech-like vocalizations as a result of delayed development of sitting posture. One of the primary reasons for the lesser complexity. Jaw movement may be accomplished in a seated position. When biomechanical support is provided, child-like speech vocalization may be produced by smacking the tongue. It is possible to accomplish both opening and closure of the mandible [45]. have carried out research A study comparing the syllable vocalizations of infants who were able to sit independently and those who were unable to sit independently at 6 months revealed that there is a difference in the frequency of their syllable vocalization. Forty-one percent of infants who were able to sit independently produced syllable vocalizations, whereas only nine percent of infants who were unable to sit independently did so. Infants that are not able to sit independently produce syllable vocalizations as they grow older [63]. According to a retrospective research, children with ASD

showed higher social skills. Children with TD were born at an average age of 9 months, with a 7.9-month delay in development [92]. These results are supported by prospective research. ASD In the first six months of life, high-risk newborns sit differently than low-risk infants. In comparison to babies at low risk of ASD, infants at high risk spend much less time sitting independently.

Babies are the most adorable thing ever [64]. This research demonstrates that slower sitting posture reduces children with ASD's ability to explore new hair while also limiting their vocal choices, resulting in decreased ability to acquire normative syllables during sitting time [54]. Autonomic nervous system disorders may affect crying timing model, and vagus nerve complex damage is associated with atypical patterns of fundamental frequency off. The autonomic nervous system is involved in respiratory control [61], and the autonomic nervous system is involved in crying timing model. The basic frequency of the human voice varies mostly as a result of muscle action and breathing. Physical qualities of the vocal cords, such as the length of the vocal cords, unit length quality, tension and stiffness may all be altered while managing the movement of the vocal folds are controlled. The vagus nerve is responsible for the majority of the innervation of the active internal laryngeal muscles [23]. Individuals with ASD disorder [59] have autonomic nervous system function, which is unusual since the autonomic nervous system is responsible for many bodily functions. The sympathetic and vagus nerves in the body are in a state of dynamic equilibrium. The increased sympathetic tone and vagal tone force weakening phenomenon observed in children with ASD [7] can lead to poor control of the vocal cords, which govern crying [84], as well as poor motor control of respiratory muscle groups, which can lead to cry-based behavior. Cry mode is activated by abnormalities such as high frequency, short length, and short duration of weeping pauses.

3.3 Perceptual Orientation Theory

Children with autism spectrum disorder (ASD) have impaired auditory processing and a poor response to spoken sound stimuli. His speech-like vocal complexity may be affected by abnormal processing [40, 87**?** , 101]. The auditory brainstem reaction elicited by speech Several studies have shown that children with ASD immaturity have impaired speech auditory processing at the brainstem level [13]. Children with autism spectrum disorders (ASD) communicate with their peers.

Infant-Directed Speech (IDS) demonstrates abnormal listening behavior. In children with autism spectrum disorder, processing and IDS did not result in brain augmentation [12]. Children with ASD have poor reactions to their names. It should also indicate that children with ASD have a more difficult time processing speech and auditory cues. ability. According to a study, 9-month-old ASD newborns are less likely to have a self-conscious reaction to their own name, which may last for up to 24 months [69] and 36 months [69] after birth [50].

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A study of babies at high risk of ASD discovered that the likelihood of developing ASD at 6 months was greater. Youngsters at risk for autism reacted less to speech sound stimuli than children at lower risk for autism [74]. Based on the facts presented above, it may be hypothesized that babies with ASD have a higher risk of developing behavioral problems. Because they do not have quasi-speech, children are less impacted by the words of their adult caregiver. Opportunities for vocal learning, which in turn influence their speech-like vocal complexity sexual development, are available to them. Recent research has shown a link between the auditory brain and speech. A relationship exists between the motor cortex and the auditory perception of speech, and this connection influences speech. According to [16], language induces reactions in the motor cortex (language production). Speech motor planning has an impact on the responses of the speech perception cortex [22]. Autism spectrum disorder (ASD) children's auditory cortex and speech-like development Further research on the interaction mechanism between the acoustic motor cortex is required.

3.4 Social Feedback Orientation Theory

The concept of a social feedback loop is defined as follows: To a certain degree, this explains why children with ASD have more complicated speech sounds than other children. a low-level phenomenon The notion highlights that adult reactions in social situations are influenced by the environment. The development of child-like speaking vocalizations, which is thought to be more common in adults, plays a role. In youngsters, it reacts to speech-like vocalizations, and in adults, it replies almost instantaneously.

Post-children are more prone than pre-children to make vocalizations that sound like speech [72]. According to Warlaumont et al. [72], a good stability and validity was employed mostly for children aged 0-4 years, but also adults. Research on the development of TD child-adult interactions in the natural world has been conducted using the Language Environment Analysis of Human Interaction Vocalization (Language ENvironment Analysis, LENA) program [49, 55, 79, 99]. Acoustic conducted a microscopic study and found that their conclusion was correct. ASD will be studied by researchers. The vocalizations of children with TD were compared, and it was discovered that ASD children's society existed. The feedback loop's efficacy is weakened as a result of this. It manifests itself primarily in two ways: first, it manifests itself as a lack of confidence in one's own abilities.One is that children with ASD produce less speech-like vocalizations; human reactions to children with ASD are influenced by the extent to which speech-like vocalizations are reduced in children with ASD. The social feedback loop then iterates over time, resulting in a feedback loop.Because of the reduction in the number of times, the number of speech-like vocalizations in children with ASD has reduced even more.

4 Research Outlook

4.1 Exploring dysphonia as a unique early recognition of children with ASD Possibility of different flags

From the above examination, it can be shown that, as compared to typically developing children, children with autism spectrum disorders (ASD) have anomalies in early childhood vocalizations. These voices, on the other hand, These characteristics may also be present in children who have other types of impairments. Examples include study into the discovery of canonical syllables in children with fragile X syndrome between 9 and 12 months of age and the reduction in the number of TD newborns between 9 and 12 months [6]. In addition, there are a number of things ASD and developmental delays are also included in this category; however, the results for these children are inconclusive. Children with ASD make less communicative vocalizations than children with Down syndrome [62], according to one research, whereas another showed no difference between the two categories of children. When it comes to communicating vocalizations, there are considerable distinctions [25]. Regarding abnormal vocalizations in non-speech-like vocalizations, [96] reported that there were no differences between children with ASD and DD, however [62] observed that children with ASD were more likely to exhibit aberrant vocalizations. Therefore, it is very required to undertake a large-scale prospective research with children who have additional problems in addition to autism. Sexual study to investigate vocal anomalies as a distinct early infancy feature of individuals with autism spectrum disorder (ASD). Possibility of recognizing future indicators in the near future.

4.2 Strengthen the research of crying in the early screening of ASD children

As previously stated, abnormal screams in children with ASD may serve as an early identifying signal. Youngsters with ASD, on the other hand, do not cry as often as other children. Early childhood screening studies have provided empirical evidence. Recent research has also shown that abnormal crying may have an impact on outcomes in children with autism spectrum disorder (ASD) [31]), since caregivers observed unusual crying in children with ASD [31]. The inability to comprehend has an impact on the quality of treatment [9]. Furthermore, parents are better able to discern the cries of children with ASD from the cries of children with TD's. For example, one research discovered that babies with ASD and newborns with TD had similar outcomes. Parents of babies with ASD reported that their children's cries were more upsetting and less frequently than those of their peers. As is customary [29]. Because of this, it is important and essential for the future.

A proposed investigation of the use of weeping in early childhood screening for autism spectrum disorder. Both painful and non-painful sobbing may be utilized as samples in screening investigations, depending on the situation. Non-painful cry samples may be derived from earlier research in which newborns were observed in their natural environment (e.g., [9]). Painful weeping may be a more sensitive early signal, and it is also more likely to be acquired in a standardized setting, according to the researchers. For example, you may create a collection of pain-type screams

caused by babies who have been immunized with a vaccine. add The investigation of loud crying in the early screening of children with ASD is not only advantageous, but it is also necessary. It will also aid in the clarification of the importance of weeping in early screening, which will in turn aid in early intervention.

4.3 Exploring automated learning based on the most predictive set of acoustic parameters learning classification model

Speech-like articulation complexity, speech-like communicative articulation, and non-speech-like speech are some of the most often utilized analytical markers for vocalization, as previously discussed. The basic frequency of talking, sobbing, and other such expressions. Several recent research have used non-verbal vocalizations or a collection of acoustic characteristics for speech-like vocalizations in children with ASD Classification prediction (for example, [58, 78]) in children with ASD Classification. Cross-validation revealed that when it came to differentiating children with ASD from their peers, Childhood and Tourette's Syndrome [78, 81] have shown that childhood acoustic features have high classification accuracy for gender. The most predictive Sexual acoustic information, on the other hand, was not recorded by any of these research. For example, [81] conducted a prospective babbling, babbling, babbling, babbling, babbling, babbling, babbling, babbling, babbling study.

The acoustic features of vocalizations such as weeping are investigated, and based on the fundamental frequency, a classification system is developed. Support vector machines (linear kernel support vector machines) and probabilistic neural networks (PNNs) are used to classify more than 20 auditory properties such as formant and sound intensity (probabilistic neural network classifiers) The model correctly categorizes youngsters with a 97 percent accuracy rate. To conduct their research, [78] conducted a retrospective study of younger children with autism spectrum disorder (ASD). They examined the basic frequency, amplitude and range of babbling, as well as their internal more specialized components. [39] developed a standard acoustic parameter set consisting of 88 parameters, which is implemented using support vector machines and single-layer bidirectional long short-term memory. Seventy-five percent of ASD babies and TD babies are accurately classified using a neural network (1-layer bidirectional long short-term memory neural network). It can be observed that the researchers looked at a variety of various sorts. A lot of auditory characteristics influence the accuracy of ASD prediction, but the best prediction is determined by a combination of these parameters. The acoustic parameters that have been measured are not yet known.

Recent research has also shown that there are changes in the acoustic parameter set that are based on gender. Khozaei and colleagues employed timbre and pitch-intensity-related sound in their research. The physiologic parameters of ten male ASD children and ten male TD children were measured and compared. The scream of the kid is utilized to train a classification model and create a subset instance of the class (subset instance) The model is then changed to 2853 months, and the linguistic ability is about 12 months. In the ASD babies and TD infants 18-51 months class, it was discovered that male children were identified more correctly than female children in both categories. The proportion of children's height is 7 percent [58]. Aside from that, the acoustic parameters of the Meta-analysis suggest that acoustic characteristics are quite promising for children with autism spectrum disorder. Detection of distinguishing characteristics, such as ratios of numerous auditory metrics, in automatically taught models. Single acoustic parameter discrimination has a greater accuracy than several acoustic parameters [42]. As a result, future research may develop optimum predictions using the Acoustic parameter set of effect and establish an autonomous learning classification model, among other things. A more sophisticated method to early screening of children with autism spectrum disorder (ASD) is provided, increasing the likelihood of being recognized sooner.

4.4 In-depth exploration of the influence of motivation on children with ASD

A study published in the journal Nature Communications demonstrates that speech-like vocalizations are intrinsically driven. It develops gradually as a result of social contact with adults in a group setting. Despite this, several studies have recently started to investigate the effects of intrinsic drive and social incentive on the development of speech-like vocalizations in newborns at high risk for autism spectrum disorder (ASD) [**?**]. The majority of empirical research in this topic, however, is fairly limited. Its drawbacks, particularly the lack of desire and a lack of a structured environment for children with confirmed ASD ,Data based on empirical research on the link between speech and vocalization. First and foremost, we will be able to dig further into the subject in the future. The influence of intrinsic motivation on the complexity of speech-like utterances in children with autism spectrum disorder (ASD) is explored in this process. Examples include intrinsic drive for specific interests in children with autism spectrum disorder (ASD). What effect does this have on the sophistication of their vocalizations that sound like speech? Computer In the TD baby class, modeling is an automated and efficient approach of teaching. The computer modeling approach has been used in the development of speech vocalization, and we may be able to apply it in the future to investigate

the intrinsic motivation for speech-like vocalization in children with Autism Spectrum Disorder (ASD). The ramifications of complexity. Second, to investigate the role of social motivation in the development of ASD.Complications in vocalization complexity associated with child-like speech The influence of social motivation Children recognize and respond to social signals, get social incentives, and sustain social ties [17], allowing them to develop socially acceptable behaviors. In contact, it is possible to acquire vocalizations that are more similar to speech. The Society for Children with Autism Spectrum Disorders The mechanisms through which motivational deficiencies have an impact on their speech-like vocalization complex are being investigated. What about the sexual aspect? In the future, it will be required to do further study in this area.

4.5 Further research on the causes of abnormal speech sounds in children with ASD mechanism

Because of the immaturity of the neuromotor system and its link with language Interactions in the speech-auditory perceptual cortex, which may be present in children with ASD, as previously stated A significant contributing factor to improper speech articulation difficulty. Children with Autism Spectrum Disorders, on the other hand, It is still unknown what the neurological process is that allows youngsters to produce speech. future Children with Autism Spectrum Disorders There are two approaches that may be used to investigate the brain mechanisms of children's speech production. Research. The possibility of looking at ASD from the viewpoint of speech apraxia is one possibility; on the other hand, we may look at it from the standpoint of autism. Children's dysphonia is caused by neural processes. Febrile spasms are a kind of movement condition that affects the motor coordination necessary for speech production [3]. According to research, apraxia of speech exists. Children with ASD may have a prevalence as high as 60 percent between the ages of 24 and 55 months [91]. As a result, new study endeavors have been made With autism spectrum disorder, the average age of a child with speech apraxia will be estimated to be 56 months. A comparison of the nervous systems of children and age-matched children with speech apraxia was made.Compare. It has been shown that children with speech apraxia have a greater capacity to communicate. The parietal lobe (limb) and frontal lobes (Upper gyrus) are the most affected by abnormal brain anatomy (paracentral, triangular) ASD is associated with increased cerebral volume. When it comes to youngsters, the majority of the growth in cerebral volume is dispersed in their social communication abilities. The frontotemporal lobes are crucial for development of the brain [20]. future The inclusion of children with ASD who do not talk or speak less than they should in studies is still ongoing. Development of the speech auditory cortex in children with ASD, on the other hand, is important. Research into the mechanism of interaction with speech-like vocal motor cortex is ongoing. According to research conducted on TD newborns, speech-like vocalizations and listening skills are important. Mappings between sensory impressions are present even before children begin to talk, according to research. Auditory discrimination of normative syllables by oral motor inhibition in 1-month-old babies of neural responses has been shown in the laboratory [18]. for children with autism spectrum disorders.The results of extensive study in the area of children may give support for their class language. New evidence for brain processes underlying the evolution of vocalizations.

References

[1] J.M. Acevedo-Valle, C. Angulo, and C. Moulin-Frier, *Autonomous discovery of motor constraints in an intrinsically motivated vocal learner*, IEEE Trans. Cogn. Dev. Syst. **10** (2018), no. 2, 314–325.

[2] L.B. Adamson, R. Bakeman, K. Suma, and D.L. Robins, *An expanded view of joint attention: Skill, engagement, and language in typical development and autism*, Child Dev. **90** (2019), no. 1.

[3] N. Akhtar, V.K. Jaswal, J. Dinishak, and C. Stephan, *On social feedback loops and cascading effects in autism: A commentary on Warlaumont, Richards, Gilkerson, and Oller (2014)*, Psych. Sci. **27** (2016), no. 11, 1528–1530.

[4] American Psychiatric Association, *Diagnostic and statistical manual of mental disorders (DSM-5-TR)*, 2013.

[5] E.C. Bacon, E. Courchesne, C.C. Barnes, D. Cha, S. Pence, L. Schreibman, A.C. Stahmer, and K. Pierce, *Rethinking the idea of late autism spectrum disorder onset*, Development and Psychopathology **30** (2018), no. 2, 553–569.

[6] K. Belardi, L.R. Watson, R.A. Faldowski, H. Hazlett, E. Crais, G.T. Baranek, C. McComish, E. Patten, and D.K. Oller, *A retrospective video analysis of canonical babbling and volubility in infants with fragile X syndrome at 9–12 months of age*, J. Autism Dev. Disord. **47** (2017), no. 4, 1193–1206.

[7] T.W. Benevides and S.J. Lane, *A review of cardiac autonomic measures: Considerations for examination of physiological response in children with autism spectrum disorder*, J. Autism Dev. Disord. **45** (2015), no. 2, 560–575.

[8] F. Bonnet-Brilhault, T.A. Rajerison, C. Paillet, M. Guimard-Brunault, A. Saby, L. Ponson, G. Tripi, J. Malvy, and S. Roux, *Autism is a prenatal disorder: Evidence from late gestation brain overgrowth: Prenatal brain overgrowth in autism*, Autism Res. **11** (2018), no. 12, 1635–1642.

[9] M. Bornstein, K. Costlow, A. Truzzi, and G. Esposito, *Categorizing the cries of infants with ASD versus typically developing infants: A study of adult accuracy and reaction time*, Res. Autism Spect. Disord. **31** (2016), 66–72.

[10] S. Boterberg, T. Charman, P.B. Marschik, S. Bölte, and H. Roeyers, *Regression in autism spectrum disorder: A critical overview of retrospective findings and recommendations for future research*, Neuroscience & Biobehavioral Reviews **102** (2019), 24–55.

[11] S. Brown, Y. Yuan, and M. Belyk, *Evolution of the speech-ready brain: The voice/jaw connection in the human motor cortex*, J. Comp. Neuro. **529** (2021), no. 5, 1018–1028.

[12] F. Chen, H. Zhang, H. Ding, S. Wang, G. Peng, and Y. Zhang, *Neural coding of formant-exaggerated speech and nonspeech in children with and without autism spectrum disorders*, Autism Res. **14** (2021), no. 7, 1357–1374.

[13] J. Chen, C. Liang, Z. Wei, Z. Cui, X. Kong, C.-j. Dong, Y. Lai, Z. Peng, and G. Wan, *Atypical longitudinal development of speech-evoked auditory brainstem response in preschool children with autism spectrum disorders*, Autism Res. **12** (2019), no. 7, 1022–1031.

[14] K. Chenausky, C. Nelson, and H. Tager-Flusberg, *Vocalization Rate and Consonant Production in Toddlers at High and Low Risk for Autism*, J. Speech Language Hear. Res. **60** (2017), no. 4, 865–876.

[15] N. Chericoni, D. de Brito Wanderley, V. Costanzo, A. Diniz-Gonçalves, M. Leitgel Gille, E. Parlato, D. Cohen, F. Apicella, S. Calderoni, and Filippo. Muratori, *Pre-linguistic vocal trajectories at 6–18 months of age as early markers of autism*, Front. Psych. **7** (2016).

[16] C. Cheung, L.S. Hamiton, K. Johnson, and E.F. Chang, *The auditory representation of speech sounds in human motor cortex*, eLife **5** (2016), e12577.

[17] C. Chevallier, G. Kohls, V. Troiani, E.S. Brodkin, and R.T. Schultz, *The social motivation theory of autism*, Trends Cogn. Sci. **16** (2012), no. 4, 231–239.

[18] D. Choi, G. Dehaene-Lambertz, M. Peña, and J.F. Werker, *Neural indicators of articulator-specific sensorimotor influences on infant speech perception*, Proc. Nat. Acad. Sci. **118** (2021), no. 20, e2025043118.

[19] C.C. Clements, A.R. Zoltowski, L.D. Yankowitz, B.E. Yerys, R.T. Schultz, and J.D. Herrington, *Evaluation of the social motivation hypothesis of autism: A systematic review and meta-analysis*, JAMA Psychiatry **75** (2018), no. 8, 797–808.

[20] E. Conti, A. Retico, L. Palumbo, G. Spera, P. Bosco, L. Biagi, S. Fiori, M. Tosetti, P. Cipriani, G. Cioni, F. Muratori, A. Chilosi, and S. Calderoni, *Autism spectrum disorder and childhood apraxia of speech: Early language-related hallmarks across structural MRI study*, J. Personal. Med. **10** (2020), no. 4, E275.

[21] M. Cychosz, A. Cristia, E. Bergelson, M. Casillas, G. Baudet, A.S. Warlaumont, C. Scaff, L. Yankowitz, and A. Seidl, *Vocal development in a large-scale crosslinguistic corpus*, preprint, PsyArXiv, December 2019.

[22] A. Daliri and L. Max, *Modulation of auditory responses to speech vs. nonspeech stimuli during speech movement planning*, Front. Human Neurosci. **10** (2016), 234.

[23] J.W. Dankbaar and F.A. Pameijer, *Vocal cord paralysis: Anatomy, imaging and pathology*, Insights Imag **5** (2014), no. 6, 743–751.

[24] S.I. Di Domenico and R.M. Ryan, *The emerging neuroscience of intrinsic motivation: A new frontier in self-determination research*, Front. Human Neurosci. **11** (2017), 145.

[25] D. Dow, T.N. Day, T.J. Kutta, C. Nottke, and A.M. Wetherby, *Screening for autism spectrum disorder in a naturalistic home setting using the systematic observation of red flags (SORF) at 18–24 months*, Autism Res. **13** (2020), no. 1, 122–133.

[26] D. Dow, W. Guthrie, S.T. Stronach, and A.M. Wetherby, *Psychometric analysis of the systematic observation of red flags for autism spectrum disorder in toddlers*, Autism **21** (2017), no. 3, 301–309.

[27] N. Eichert, D. Papp, R.B. Mars, and K.E. Watkins, *Mapping human laryngeal motor cortex during vocalization*,

Cerebral Cortex **30** (2020), no. 12, 6254–6269.

[28] S.L. Elmlinger, J.A. Schwade, and M.H. Goldstein, *The ecology of prelinguistic vocal learning: parents simplify the structure of their speech in response to babbling*, J. Child Language **46** (2019), no. 05, 998–1011.

[29] M.S. English, E.J. Tenenbaum, T.P. Levine, B.M. Lester, and S.J. Sheinkopf, *Perception of cry characteristics in 1-month-old infants later diagnosed with autism spectrum disorder*, J. Autism Dev. Disord. **49** (2019), no. 3, 834–844.

[30] G. Esposito, M. del Carmen Rostagno, P. Venuti, J.D. Haltigan, and D.S. Messinger, *Brief report: Atypical expression of distress during the separation phase of the strange situation procedure in infant siblings at high risk for ASD*, J. Autism Dev. Disord. **44** (2014), no. 4, 975–980.

[31] G. Esposito, N. Hiroi, and M.L. Scattoni, *Cry, baby, cry: Expression of distress as a biomarker and modulator in autism spectrum disorder*, Int. J. Neuropsychopharmacology **20** (2017), no. 6, 498–503.

[32] G. Esposito, J. Nakazawa, P. Venuti, and M.H. Bornstein, *Perceptions of distress in young children with autism compared to typically developing children: A cultural comparison between Japan and Italy*, Res. Dev. Disabil. **33** (2012), no. 4, 1059–1067.

[33] ———, *Componential deconstruction of infant distress vocalizations via tree-based models: A study of cry in autism spectrum disorder and typical development*, Res. Dev. Disabil. **34** (2013), no. 9, 2717–2724.

[34] G. Esposito, S. Valenzi, T. Islam, and M.H. Bornstein, *Three physiological responses in fathers and non-fathers' to vocalizations of typically developing infants and infants with Autism Spectrum Disorder*, Res. Dev. Disabil. **43-44** (2015), 43–50.

[35] G. Esposito and P. Venuti, *Comparative analysis of crying in children with autism, developmental delays, and typical development*, Focus on Autism Dev. Disabil. **24** (2009), no. 4, 240–247.

[36] ———, *Developmental changes in the fundamental frequency (f0) of infants' cries: a study of children with autism spectrum disorder*, Early Child Dev. Care **180** (2010), no. 8, 1093–1102.

[37] ———, *Understanding early communication signals in autism: A study of the perception of infants' cry*, J. Intel. Disabil. Res. **54** (2010), no. 3, 216–223.

[38] A. Estes, J. Munson, S.J. Rogers, J. Greenson, J. Winter, and G. Dawson, *Long-term outcomes of early intervention in 6-year-old children with autism spectrum disorder*, J. Amer. Acad. Child Adolescent Psychiatry **54** (2015), no. 7, 580–587.

[39] F. Eyben, K.R. Scherer, B.W. Schuller, J. Sundberg, E. Andre, C. Busso, L.Y. Devillers, J. Epps, P. Laukka, S.S. Narayanan, and K.P. Truong, *The Geneva minimalistic acoustic parameter set (GeMAPS) for voice research and affective computing*, IEEE Trans. Affect. Comput. **7** (2016), no. 2, 190–202.

[40] M.G. Filipe, L. Watson, S.G. Vicente, and S. Frota, *Atypical preference for infant-directed speech as an early marker of autism spectrum disorders? A literature review and directions for further research*, Clinic. Linguist. Phonetics **32** (2018), no. 3, 213–231.

[41] T.W. Frazier, E.W. Klingemier, C.J. Anderson, G.W. Gengoux, E.A. Youngstrom, and A.Y. Hardan, *A longitudinal study of language trajectories and treatment outcomes of early intensive behavioral intervention for autism*, J. Autism Dev. Disord. **51** (2021), no. 12, 4534–4550.

[42] R. Fusaroli, A. Lambrechts, D. Bang, D.M. Bowler, and S.B. Gaigg, *Is voice a marker for autism spectrum disorder? A systematic review and meta-analysis*, Autism Res.: Offic. J. Int. Soc. Autism Res. **10** (2017), no. 3, 384–407.

[43] D. Garrido, L.R. Watson, G. Carballo, R. Garcia-Retamero, and E.R. Crais, *Infants at-risk for autism spectrum disorder: Patterns of vocalizations at 14 months*, Autism Res.: Offic. J. Int. Soc. Autism Res. **10** (2017), no. 8, 1372–1383.

[44] R. Goel, J.S. Hong, R.L. Findling, and N.Y. Ji, *An update on pharmacotherapy of autism spectrum disorder in children and adolescents*, Int. Rev. Psychiatry (Abingdon, England) **30** (2018), no. 1, 78–95.

[45] Jordan R. Green, Christopher A. Moore, and Kevin J. Reilly, *The sequential development of jaw and lip control for speech*, J. Speech Language Hear. Res. **45** (2002), no. 1, 66–79.

[46] R. Grove, I. Roth, and R.A. Hoekstra, *The motivation for special interests in individuals with autism and controls: Development and validation of the special interest motivation scale*, Autism Res.: Offic. J. Int. Soc. Autism Res. **9** (2016), no. 6, 677–688.

[47] Q. Guillon, B. Rogé, M.H. Afzali, S. Baduel, J. Kruck, and N. Hadjikhani, *Intact perception but abnormal orientation towards face-like objects in young children with ASD*, Sci. Rep. **6** (2016), no. 1, 22119.

[48] S.R. Hage, *Dual neural network model of speech and language evolution: new insights on flexibility of vocal production systems and involvement of frontal cortex*, Current Opin. Behav. Sci. **21** (2018), 80–87.

[49] A.L. Harbison, T.G. Woynaroski, J. Tapp, J.W. Wade, A.S. Warlaumont, and P.J. Yoder, *A new measure of child vocal reciprocity in children with autism spectrum disorder*, Autism Res.: Offic. J. Int. Soc. Autism Res. **11** (2018), no. 6, 903–915.

[50] B. Hatch, A.-M. Iosif, A. Chuang, L. de la Paz, S. Ozonoff, and M. Miller, *Longitudinal differences in response to name among infants developing ASD and risk for ADHD*, J. Autism Dev. Disord. **51** (2021), no. 3, 827–836.

[51] H.C. Hazlett, H. Gu, B.C. Munsell, S.H. Kim, M. Styner, J.J. Wolff, J.T. Elison, M.R. Swanson, H. Zhu, K.N. Botteron, D.L. Collins, J.N. Constantino, S.R. Dager, A.M. Estes, A.C. Evans, V.S. Fonov, G. Gerig, P. Kostopoulos, R.C. McKinstry, J. Pandey, S. Paterson, J.R. Pruett, R.T. Schultz, D.W. Shaw, L. Zwaigenbaum, J. Piven, J. Piven, H.C. Hazlett, C. Chappell, S.R. Dager, A.M. Estes, D.W. Shaw, K.N. Botteron, R.C. McKinstry, J.N. Constantino, J.R. Pruett Jr, R.T. Schultz, S. Paterson, L. Zwaigenbaum, J.T. Elison, J.J. Wolff, A.C. Evans, D.L. Collins, G.B. Pike, V.S. Fonov, P. Kostopoulos, S. Das, G. Gerig, M. Styner, Core H. Gu, The IBIS Network, Clinical Sites, Data Coordinating Center, Image Processing Core, and Statistical Analysis, *Early brain development in infants at high risk for autism spectrum disorder*, Nature **542** (2017), no. 7641, 348–351.

[52] H.C. Hazlett, M.D. Poe, G. Gerig, M. Styner, C. Chappell, R.G. Smith, C. Vachet, and J. Piven, *Early brain overgrowth in autism associated with an increase in cortical surface area before age 2 years*, Arch. Gen. Psychiat. **68** (2011), no. 5, 467–476.

[53] P. Heymann, J.B. Northrup, K.L. West, M.V. Parladé, N.B. Leezenbaum, and J.M. Iverson, *Coordination is key: Joint attention and vocalisation in infant siblings of children with autism spectrum disorder*, Int. J. Language Commun. Disord. **53** (2018), no. 5, 1007–1020.

[54] J.M. Iverson, *Early motor and communicative development in infants with an older sibling with autism spectrum disorder*, J. Speech Language Hear. Res. **61** (2018), no. 11, 2673–2684.

[55] R.M. Jones, D. Plesa Skwerer, R. Pawar, A. Hamo, C. Carberry, E.L. Ajodan, D. Caulley, M.R. Silverman, S. McAdoo, S. Meyer, A. Yoder, M. Clements, C. Lord, and H. Tager-Flusberg, *How effective is LENA in detecting speech vocalizations and language produced by children and adolescents with ASD in different contexts?*, Autism Res. **12** (2019), no. 4, 628–635.

[56] G. Kaushik and K.S. Zarbalis, *Prenatal neurogenesis in autism spectrum disorders*, Front. Chem. **4** (2016).

[57] R.D. Kent, *Nonspeech oral movements and oral motor disorders: A narrative review*, Amer. J. Speech Language Path. **24** (2015), no. 4, 763–789.

[58] A. Khozaei, H. Moradi, R. Hosseini, H. Pouretemad, and B. Eskandari, *Early screening of autism spectrum disorder using cry features*, PLOS ONE **15** (2020), no. 12, e0241690.

[59] X. Kong, J. Liu, K. Liu, M. Koh, R. Tian, C. Hobbie, M. Fong, Q. Chen, M. Zhao, C. Budjan, and J. Kong, *Altered autonomic functions and gut microbiome in individuals with autism spectrum disorder (ASD): Implications for assisting ASD screening and diagnosis*, J. Autism Dev. Disord. **51** (2021), no. 1, 144–157.

[60] V. Kumar, P.L. Croxson, and K. Simonyan, *Structural organization of the Laryngeal motor cortical network and its implication for evolution of speech production*, J. Neurosci.: Offic. J. Soc. Neurosci. **36** (2016), no. 15, 4170–4181.

[61] L.L. LaGasse, A.R. Neal, and B.M. Lester, *Assessment of infant cry: acoustic cry analysis and parental perception*, Mental Retard. Dev. Disabil. Res. Rev. **11** (2005), no. 1, 83–93.

[62] K.S. Lee, Y.J. Shin, H.J. Yoo, G.J. Lee, J. Ryu, O. Son, and S.W. Cho, *Vocalization of emotiona and social expressions in Korean-speaking toddlers with autism spectrum disorder and those with developmental delay*, Yonsei Med. J. **59** (2018), no. 3, 425–430.

[63] N.B. Leezenbaum, *Posture development and vocalization production in infants at heightened risk for autism spectrum disorder*, (2016), Publisher: University of Pittsburgh.

[64] N.B. Leezenbaum and J.M. Iverson, *Trajectories of posture development in infants with and without familia risk for autism spectrum disorder*, J. Autism Dev. Disord. **49** (2019), no. 8, 3257–3277.

[65] B.M. Lester and L.L. La Gasse, *Crying. encyclopedia of infant and early childhood development*, (2020), 358–369, Publisher: Academic, San Diego.

[66] C. Lord, T.S. Brugha, T. Charman, J. Cusack, G. Dumas, T. Frazier, E.J.H. Jones, R.M. Jones, A. Pickles, M.W. State, J.L. Taylor, and J. Veenstra-VanderWeele, *Autism spectrum disorder*, Nature Rev. Disease Primers **6** (2020), no. 1, 5.

[67] M.J Maenner, K.A. Shaw, J. Baio, A. Washington, M. Patrick, M. DiRienzo, D.L. Christensen, L.D. Wiggins, S. Pettygrove, and J.G. Andrews, *Prevalence of autism spectrum disorder among children aged 8 years—autism and developmental disabilities monitoring network, 11 sites, United States, 2016*, MMWR Surveil. Summ. **69** (2020), no. 4, 1, Publisher: Centers for Disease Control and Prevention.

[68] J. McDaniel, P. Yoder, A. Estes, and S.J. Rogers, *Validity of vocal communication and vocal complexity in young children with autism spectrum disorder*, J. Autism Dev. Disord. **50** (2020), no. 1, 224–237.

[69] M. Miller, A.-M. Iosif, M. Hill, G.S. Young, A.J. Schwichtenberg, and S. Ozonoff, *Response to name in infants developing autism spectrum disorder: A prospective study*, J. Pediatrics **183** (2017), 141–146.e1.

[70] S. Nathani, D.J. Ertmer, and R.E. Stark, *Assessing vocal development in infants and toddlers*, Clinic. Linguist. Phonet. **20** (2006), no. 5, 351–369.

[71] D. Kimbrough Oller, M. Caskey, H. Yoo, E.R. Bene, Y. Jhang, C.-C. Lee, D.D. Bowman, H.L. Long, E.H. Buder, and B. Vohr, *Preterm and full term infant vocalization and the origin of language*, Sci. Rep. **9** (2019), no. 1, 14734.

[72] D. Kimbrough Oller, U. Griebel, and A.S. Warlaumont, *Vocal development as a guide to modeling the evolution of language*, Topics in Cognitive Science **8** (2016), no. 2, 382–392.

[73] Y. Ozturk, A. Bizzego, G. Esposito, C. Furlanello, and P. Venuti, *Physiological and self-report responses of parents of children with autism spectrum disorder to children crying*, Research in Developmental Disabilities **73** (2018), 31–39.

[74] S.J. Paterson, J.J. Wolff, J.T. Elison, B. Winder-Patel, L. Zwaigenbaum, A. Estes, J. Pandey, R.T. Schultz, K. Botteron, S.R. Dager, H.C. Hazlett, J. Piven, and IBIS Network, *The importance of temperament for understanding early manifestations of autism spectrum disorder in high-risk infants*, J. Autism Dev. Disord. **49** (2019), no. 7, 2849–2863.

[75] E. Patten, K. Belardi, G.T. Baranek, L.R. Watson, J.D. Labban, and D.K. Oller, *Vocal patterns in infants with autism spectrum disorder: canonical babbling status and vocalization frequency*, J. Autism Dev. Disord. **44** (2014), no. 10, 2413–2428.

[76] R. Paul, Y. Fuerst, G. Ramsay, K. Chawarska, and A. Klin, *Out of the mouths of babes: vocal production in infant siblings of children with ASD*, J. Child Psych. Psychiat. Allied Discip. **52** (2011), no. 5, 588–598.

[77] A.M. Plumb and A.M. Wetherby, *Vocalization development in toddlers with autism spectrum disorder*, J. Speech Language Hear. Research **56** (2013), no. 2, 721–734.

[78] F.B. Pokorny, B. Schuller, P.B. Marschik, R. Brueckner, P. Nyström, N. Cummins, S. Bölte, C. Einspieler, and T. Falck-Ytter, *Earlier identification of children with autism spectrum disorder: An automatic vocalisation-based approach*, Interspeech 2017, ISCA, August 2017, pp. 309–313.

[79] J.A. Richards, D. Xu, J. Gilkerson, U. Yapanel, S. Gray, and T. Paul, *Automated assessment of child vocalization development using LENA*, J. Speech Language Hear. Res. **60** (2017), no. 7, 2047–2063.

[80] L-A.R. Sacrey, L. Zwaigenbaum, S. Bryson, J. Brian, I.M. Smith, W. Roberts, P. Szatmari, T. Vaillancourt, C. Roncadin, and N. Garon, *Screening for behavioral signs of autism spectrum disorder in 9-month-old infant siblings*, J. Autism Dev. Disord. **51** (2021), no. 3, 839–848.

[81] J.F. Santos, N. Brosh, T.H. Falk, L. Zwaigenbaum, S.E. Bryson, W. Roberts, I.M. Smith, P. Szatmari, and J.A.

Brian, *Very early detection of autism spectrum disorders based on acoustic analysis of pre-verbal vocalizations of 18-month old toddlers*, IEEE Int. Conf. Acoustics Speech Signal Proc., May 2013, ISSN: 2379-190X, pp. 7567–7571.

[82] E. Schoen, R. Paul, and K. Chawarska, *Phonology and vocal behavior in toddlers with autism spectrum disorders*, Autism Res.: Offic. J. Int. Soc. Autism Res. **4** (2011), no. 3, 177–188.

[83] S.J. Sheinkopf, J.M. Iverson, M.L. Rinaldi, and B.M. Lester, *Atypical cry acoustics in 6-month-old infants at risk for autism spectrum disorder*, Autism Res.: Offic. J. Int. Soc. Autism Res. **5** (2012), no. 5, 331–339 (eng).

[84] S.J. Sheinkopf, G. Righi, C.J. Marsit, and B.M. Lester, *Methylation of the Glucocorticoid Receptor (NR3C1) in Placenta is associated with infant cry acoustics*, Frontiers in Behavioral Neuroscience **10** (2016).

[85] S. Shumway and A.M. Wetherby, *Communicative acts of children with autism spectrum disorders in the second year of life*, Journal of Speech, Language, and Hearing Research **52** (2009), no. 5, 1139–1156.

[86] J. Sigafoos and H. Waddington, *6 year follow-up supports early autism intervention*, Lancet **388** (2016), no. 10059, 2454–2455.

[87] L.N. Soskey, P.D. Allen, and L. Bennetto, *Auditory spatial attention to speech and complex non-speech sounds in children with autism spectrum disorder*, Autism Res.: Offic. J. Int. Soc. Autism Res. **10** (2017), no. 8, 1405–1416 (eng).

[88] K. Supekar, J. Kochalka, M. Schaer, H. Wakeman, S. Qin, A. Padmanabhan, and V. Menon, *Deficits in mesolimbic reward pathway underlie social interaction impairments in children with autism*, Brain: J. Neuro. **141** (2018), no. 9, 2795–2805.

[89] M.R. Talbott, C.A. Nelson, and H. Tager-Flusberg, *Maternal vocal feedback to 9-month-old infant siblings of children with asd*, Autism Res.: Offic. J. Int. Soc. Autism Res. **9** (2016), no. 4, 460–470.

[90] C. Tan, V. Frewer, G. Cox, K. Williams, and A. Ure, *Prevalence and age of onset of regression in children with autism spectrum disorder: A systematic review and meta-analytical update*, Autism Research **14** (2021), no. 3, 582–598.

[91] C. Tierney, S. Mayes, S.R. Lohs, A. Black, E. Gisin, and M. Veglia, *How valid is the checklist for autism spectrum disorder when a child has apraxia of speech?*, J. Dev. Behav. Pediat. **36** (2015), no. 8, 569–574.

[92] I. Ucuz and A. Uzun Çiçek, *Artificial neural networks based-prediction of autism spectrum disorder*, **5** (2020), 78–82.

[93] L.M. Unwin, I. Bruz, M.T. Maybery, V. Reynolds, N. Ciccone, C. Dissanayake, M. Hickey, and A.J.O. Whitehouse, *Acoustic properties of cries in 12-month old infants at high-risk of autism spectrum disorder*, J. Autism Dev. Disord. **47** (2017), no. 7, 2108–2119.

[94] M. van 't Hof, C. Tisseur, I. van Berckelear-Onnes, A. van Nieuwenhuyzen, A.M. Daniels, M. Deen, H.W. Hoek, and W.A. Ester, *Age at autism spectrum disorder diagnosis: A systematic review and meta-analysis from 2012 to 2019*, Autism: Int. J. Res. Practice **25** (2021), no. 4, 862–873.

[95] P. Venuti, A. Caria, G. Esposito, N. De Pisapia, M.H. Bornstein, and S. de Falco, *Differential brain responses to cries of infants with autistic disorder and typical development: an fMRI study*, Res. Dev. Disab. **33** (2012), no. 6, 2255–2264.

[96] A.M. Wetherby, J. Woods, L. Allen, J. Cleary, H. Dickinson, and C. Lord, *Early indicators of autism spectrum disorders in the second year of life*, J. Autism Dev. Disord. **34** (2004), no. 5, 473–493.

[97] A.M. Wetherby, J. Woods, W. Guthrie, A. Delehanty, J.A. Brown, L. Morgan, R.D. Holland, C. Schatschneider, and C. Lord, *Changing developmental trajectories of toddlers with autism spectrum disorder: Strategies for bridging research to community practice*, J. Speech Language Hear. Res. **61** (2018), no. 11, 2615–2628.

[98] B.M. Winder, R.H. Wozniak, M.V. Parladé, and J.M. Iverson, *Spontaneous initiation of communication in infants at low and heightened risk for autism spectrum disorders*, Dev. Psych. **49** (2013), no. 10, 1931–1942.

[99] T. Woynaroski, D.K. Oller, B. Keceli-Kaysili, D. Xu, J.A. Richards, J. Gilkerson, S. Gray, and P. Yoder, *The stability and validity of automated vocal analysis in preverbal preschoolers with autism spectrum disorder*, Autism Res.: Offic. J. Int. Soc. Autism Res. **10** (2017), no. 3, 508–519.

[100] T. Woynaroski, L. Watson, E. Gardner, C.R. Newsom, B. Keceli-Kaysili, and P.J. Yoder, *Early predictors of growth in diversity of key consonants used in communication in initially preverbal children with autism spectrum disorder*, J. Autism Dev. Disord. **46** (2016), no. 3, 1013–1024.

[101] S.H. Yau, J. Brock, and G. McArthur, *The relationship between spoken language and speech and nonspeech processing in children with autism: a magnetic event-related field study*, Dev. Sci. **19** (2016), no. 5, 834–852.

[102] N. Yirmiya and T. Charman, *The prodrome of autism: early behavioral and biological signs, regression, peri- and post-natal development and genetics*, J. Child Psych. Psychiat. and Allied Discip. **51** (2010), no. 4, 432–458.

[103] H. Zhou, X. Xu, W. Yan, X. Zou, L. Wu, X. Luo, T. Li, Y. Huang, H. Guan, X. Chen, M. Mao, K. Xia, L. Zhang, E. Li, X. Ge, L. Zhang, C. Li, X. Zhang, Y. Zhou, D. Ding, A. Shih, E. Fombonne, Y. Zheng, J. Han, Z. Sun, Y.-H. Jiang, Y. Wang, and LATENT-NHC Study Team, *Prevalence of autism spectrum disorder in china: A nationwide multi-center population-based study among children aged 6 to 12 years*, Neurosci. Bull. **36** (2020), no. 9, 961–971.