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Atypical Cry Acoustics in 6-Month-Old Infants at Risk for Autism Spectrum Disorder

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Abstract

This study examined differences in acoustic characteristics of infant cries in a sample of babies at risk for autism and a low-risk comparison group. Cry samples derived from vocal recordings of 6-month-old infants at risk for autism spectrum disorder (ASD; $n = 21$) and low-risk infants ($n = 18$) were subjected to acoustic analyses using analysis software designed for this purpose. Cries were categorized as either pain-related or non-pain-related based on videotape coding. At-risk infants produced pain-related cries with higher and more variable fundamental frequency (F_0) than low-risk infants. At-risk infants later classified with ASD at 36 months had among the highest F_0 values for both types of cries and produced cries that were more poorly phonated than those of nonautistic infants, reflecting cries that were less likely to be produced in a voiced mode. These results provide preliminary evidence that disruptions in cry acoustics may be part of an atypical vocal signature of autism in early life.

Keywords

autism; infancy; cry; vocalizations; acoustic analysis

This study tested whether infants at risk for autism spectrum disorders (autism or ASDs) show differences in vocal production in early infancy by examining whether infant siblings of children with autism showed alterations in acoustic properties of infant cries at 6 months of age. A common focus of early infant studies of autism has been on aspects of social responses and relatedness in early development. Findings have revealed that disruptions in social behaviors by 12 months, including poor response to name, atypical eye contact, and reduced social interest and social smiling, distinguish at-risk babies who are later diagnosed with autism [Zwaigenbaum et al., 2005]. Some studies have found alterations in social responses during the face-to-face/still-face procedure as early as 4–6 months of age, including fewer smiles directed at mothers [Cassel et al., 2007], diminished gaze to eyes relative to mouth [Merin, Young, Ozonoff, & Rogers, 2007], and less interactional synchrony between babies and mothers [Yirmiya et al., 2006]. However, in general, it has been difficult to identify robust deficits in social behaviors associated with autism in early

infancy [Ozonoff et al., 2010]. However, other atypicalities seen in childhood autism may also be investigated in infancy. For example, atypical vocal production has been studied in toddlers and young children with autism [Oller et al., 2010; Schoen, Paul, & Chawarska, 2011; Sheinkopf, Mundy, Oller, & Steffens, 2000; Woods & Wetherby, 2003]. These studies have found that autism is associated with atypical vocal quality and that such vocal parameters may help to discriminate children with or at risk for a diagnosis. Such findings lead to the prediction that differences in infant vocal production may be evident in babies at risk for or later diagnosed with autism.

Recently, Paul, Fuerst, Ramsay, Chawarska, and Klin, [2010] reported that infants at risk for autism produce lower rates of canonical syllables by 9 months but not at 6 months of age. Because this capacity to produce well-formed babbles is just emerging in early infancy, age-specific findings may reflect a floor effect for the sensitivity of phonological structure to detect differences between risk groups at young ages. Nonsegmental aspects of vocal production may be more sensitive to differences associated with autism in early infancy. Infant cries are one type of nonsegmental production that can be observed from the earliest days of life. Cry acoustics have been studied in other clinical and at-risk populations, and may be disrupted in infants at risk for autism.

Esposito and Venuti [2009, 2010] have reported differences in observer ratings of cry at 12 months of age in later-diagnosed babies from home videotapes. Observers rated the cries of infants later diagnosed with autism as having more atypical features and fewer prototypical cry patterns than babies with typical development and those with developmental delays [Esposito & Venuti, 2009]. These researchers also reported higher fundamental frequency (F_0) of cries in later-diagnosed infants vs. typically developing infants by 12 months of age [Esposito & Venuti, 2010]. Differences in infant cry acoustics have not yet been found in relation to autism earlier in development.

The production of cry is the result of air being forced through the vocal tract and over the larynx. Vibrations of the vocal folds result in the sound that is perceived by humans as crying. This sound can be described with a variety of parameters, including the loudness or amplitude of the cry, the timing of cry onset, and length of interutterance intervals. Other aspects of cries can be represented acoustically by describing features such as F_0 , voicing, and formant frequencies. F_0 is the base frequency of a cry and is perceived as pitch. Voicing, also called phonation, describes cry sounds resulting from harmonic vibration of the vocal folds. Formants (e.g. F_1 , F_2 , etc.) describe additional resonant frequencies in the sound spectrum, and in speech recognition, work can be used to describe the configuration of the vocal tract.

There is a long history of research on infant crying in populations considered at risk for developmental differences, as well as those with identified conditions [Karelitz & Fisichelli, 1962; Prechtl, Theorell, Gramsbergen, & Lind, 1969; Wasz-Hockert, Lind, Vourenkoski, Partanen, & Valanne, 1968]. This research includes more recent work describing acoustic features of infant crying in relation to risk for poor developmental outcomes [Gibbins et al., 2008; Goberman & Robb, 1999; Quick, Robb, & Woodward, 2009; Zeskind, Platzman, Coles, & Schuetze, 1996]. These results include differences in F_0 and, to some degree, other measures of vocal tract configuration (i.e. formants) in infants with perinatal risks or medical complications such as hyperbilirubinemia, prenatal substance exposure, lead exposure, or frank evidence of brain damage [see LaGasse, Neal, & Lester, 2005]. Thus, cry characteristics are an indication of neurobehavioral risk. However, crying can also be understood in the context of a biosocial model, where infant crying is seen as both a physiologic event and part of a dyadic communication system between baby and caregivers [Lester, 1984]. In relation to autism, cry acoustics may reflect underlying neurobehavioral

differences associated with the disorder and may also reflect differences in the development of the parent-infant dyad as well as being predictive of long-term developmental outcome [Lester, 1987].

Research in clinical populations has tended to focus on differences in average and maximum values of F_0 , range or variability of F_0 across cry utterances, and other measures used to describe the acoustic characteristics of cries. However, other research, especially work in typical populations, has examined features that can be described as reflecting prosodic aspects of cry sounds. Work on cry prosody focuses on aspects such as the *contour* of cry pitch [i.e. nonlinear changes in F_0 across an utterance; see, for example, Mampe, Friederici, Christophe, & Wermke, 2009 and Wermke, Mende, Manfredi, & Bruscia, 2002].

Studies of prosodic features of cry may have value in the study of infants at risk for autism given the overall delays in language, and the differences in prosodic speech characteristics are often characteristics of children and adults with autism [Tager-Flusberg, 2005]. However, in order to be consistent with prior research linking cry characteristics with perinatal risks and poor developmental outcomes, the current study examines measures of cry utterance characteristics such as the average value and variability in F_0 , as well as measures of voicing in relation to risk for autism. This level of analysis is consistent with prior research on vocal characteristics of young children with autism. For example, research has found that young children with autism produce vocalizations with less clear emotional signals [Ricks & Wing, 1975], higher rates of atypical vocalizations [Wetherby et al., 2004; Wetherby, Yonclas, & Bryan, 1989], and with atypical voicing described as highly tense or high-pitched [Sheinkopf et al., 2000]. In an acoustic framework, these vocalizations could be characterized as having high overall F_0 and unusual phonation or voicing.

In the study reported in this paper, our aim was to investigate acoustic features of cries that may be linked to arousal, regulation, and neurobehavioral integrity. As such, overall descriptions of features such as F_0 and phonation (voicing) were the focus of this study. We report initial findings of an investigation of cry production in a group of infants at risk for autism and a low-risk (LR) comparison sample. Prior findings from young children with autism and the limited number of observations of infants later diagnosed with autism led to the prediction that autism-related cry atypicalities will be found in the acoustic features of F_0 and phonation, representing the degree to which cries are voiced. Differences in the amplitude or force of cry may also be present but are more difficult to operationalize because of measurement and recording difficulties.

Methods

Participants

Participants included 21 infants (6 male, 15 female) from families in which an older child had been diagnosed with ASD (Autistic Disorder, Asperger's Disorder, or Pervasive Developmental Disorder, Not Otherwise Specified). The infants in this ASD-risk (AR) group were recruited through an ongoing study of infant siblings of children with autism. Older siblings were evaluated prior to enrollment with the Autism Diagnostic Observation Schedule [ADOS; Lord et al., 2000] by a trained clinician. For an infant to qualify for the study, the infant's older sibling had to score above the threshold for autism on the ADOS. A comparison sample of 18 LR later-born infants (eight males, ten females) with no family history of ASD was selected from a larger group participating in an ongoing longitudinal study being conducted by the second author. All participants were from full-term, uncomplicated pregnancies and came from monolingual, English-speaking households. Thirty-six infants (19 AR, 17 LR) were white non-Hispanic, two (both AR infants) were white Hispanic, and one LR infant was Asian-American. Groups did not differ in level of

parental education (the majority of parents had college degrees or completed some college), maternal age (AR mean = 35.0, standard deviation [SD] = 4.75; LR mean = 33.0, SD = 5.12), or paternal age (AR mean = 36.33, SD = 3.63; LR mean = 34.33, SD = 4.10).

AR infants were evaluated at 36 months of age to document developmental functioning and to determine diagnosis at outcome. Developmental functioning for the AR group was assessed using the Mullen scales of early learning [Mullen, 1995]. Diagnosis was determined by clinical evaluation using Diagnostic and Statistical Manual IV, Text Revision criteria, confirmed by an above-threshold score on the ADOS, using standard diagnostic algorithm cutoff scores. Three AR infants were classified as ASD at 36 months of age. Specifically, these children received a diagnosis of Autistic Disorder by a trained clinician naïve to previous study data and had ADOS scores exceeding the autism cutoff. The group and individual data for the AR group is summarized in Table 1.

Procedures

Audio-video recordings were made in the infants' homes at 6 months of age (+/- 3 days). Recordings were approximately 45 min in length. Caregivers were instructed to continue their normal activities, and infants were observed in contexts and activities typical of the time of day at which the visit took place. Recordings were made using a digital video camcorder and a wireless microphone and transmitter that was embedded in a vest the infants wore over their clothing. Placement of the microphone on the infants' clothing allowed for some degree of standardization of the distance to the infant's mouth.

Identification and coding of cry episodes—Episodes of cry and fuss vocalizations were identified from video recordings by research staff naïve to group membership. Cry episodes suitable for acoustic analysis were identified based on the absence of background noises that would interfere with the analysis (e.g. adult talk, sounds from toys, or other environmental noises). Resulting cry samples were excerpted and recorded to audiocassette for subsequent acoustic analysis (excerpting cries to audio-cassette was done for compatibility with the automated cry analysis system, described later). Cry vocalizations suitable for acoustic analysis were identified for 28 infants (17 AR, 11 LR).

Additional coding was performed to account for infant positioning, as well as the context and potential precipitants of observed cries. Infant positioning (e.g. infant prone or supine) was coded because of potential effects of position on cry production [Lin & Green, 2007]. Context characteristics included level of noise in the environment, the presence of other people in addition to the parent, and verbal and physical interactions with the baby. These coding procedures were performed in order to help rule out potential confounding influences on cry characteristics. Coding was performed by research staff naïve to group membership and later diagnoses.

In addition to coding for the presence of potential confounding factors, these observations were also the basis for staff to make an overall judgment of the potential cause or function of the cry or fuss vocalization. These were mutually exclusive dichotomous codes and included whether the cry appeared to be the result of pain or for other reasons (e.g. frustration, seeking attention, hunger, startles). The specific procedure for the coding of context and causes of cry was as follows. The time of onset of all cry episodes on the videotapes was coded to the nearest second. Coders then returned to the videotape and viewed the episode starting at 30 sec before the start of the cry and continuing to 30 sec after the start of the cry. This allowed for the observation of events or stimuli upon which coders could judge what caused the baby to cry.

The rationale for grouping cries into those that appeared to be pain-related vs. non-pain-related was twofold. First, research on cry acoustics in at risk or clinical populations has predominantly used procedures to elicit pain-related cries or has observed cries in response to specific pain-inducing naturally occurring events [e.g. vaccinations; see LaGasse et al., 2005]. The present study utilized naturally occurring cries without a standard eliciting procedure. Grouping cries in this way provided an analog cry assessment to prior research. Second, because pain cries may differ from no-pain cries in acoustic features, separating these cries out in our analyses reduced some degree of nonspecific variability in the cry measurement. Reliability of coding context and cry precipitants was assessed by double-coding all cry episodes. Independent ratings were found to have high levels of agreement for differentiating pain- from non-pain-related cries (interrater agreement = 87%; Kappa = 0.75).

Using these procedures, we identified cries that were pain-related and non-pain-related for the AR and LR groups. The first utterance of each cry was analyzed. Prior experience has indicated that initial cry utterances may be most sensitive to group differences and that these early utterances are particularly characteristic of pain-elicited cries [Branco, Fekete, Rugolo, & Rehder, 2007; LaGasse et al., 2005]. Characteristics of the full length of a cry episode (e.g. length of crying) are not reported because of the naturalistic setting and variation in parental responses to infant signs of distress. For the AR group, there were seven infants with pain-related cries and ten infants with non-pain-related cries. For the LR group, there were five infants with pain-related cries and six infants with non-pain-related cries. Some babies (four AR and seven LR) did not produce cries that could be analyzed acoustically.

Acoustic analysis procedures—The resulting corpus of cry episodes was subjected to acoustic analysis using a computer system that has been specifically designed and well validated to perform cry analyses in infants [Corwin et al., 1992, 1995; Lester et al., 1991]. Cry signals were filtered above 5 kHz and digitized at 10 kHz. Cry units were defined as a cry during the expiratory phase of respiration lasting at least 0.5 sec. These samples were subjected to fast Fourier transform to compute the log magnitude spectrum for each 25-msec analysis block within a cry unit, and summary variables were calculated for each analysis block. These block-level data were aggregated to yield summary statistics for a cry episode and for cry utterances within cry episodes.

Dependent measures produced by the cry analysis system are listed in Table 2. Of primary interest for this study were measures of F_0 and phonation. F_0 is defined as the basic frequency of the cry and is perceived as “pitch”. Phonation refers to cry segments (% of measurement blocks) resulting from harmonic vibration of the vocal folds. The system produced other variables that were not the focus of a priori analyses but were investigated given the exploratory nature of this research, including cry amplitude and formants (F_1 and F_2). In addition to testing for group differences, we examined the distribution of cry parameters by plotting the data of children with confirmed 36-month diagnoses of ASD relative to the nonautistic children.

Results

Group Analyses

Independent *t*-tests of means were conducted to investigate group differences in acoustic cry features, with separate analyses being run for non-pain- and pain-related cries. Initial tests included the AR infants who were later classified with ASD, and follow-up tests were conducted, where appropriate, to determine the degree to which these infants influenced statistically significant differences. These data and statistical results are detailed in Table 3.

Results revealed that AR infants produced pain-related cries with significantly higher mean F_0 than did the LR group, $t(10) = 2.82$, $P = 0.018$. The effect size of this difference (Cohen's d) was 1.65, indicating that there was little overlap between AR and LR infants on this measure. In addition, the pain-related cries of the AR group had a greater range of F_0 than the LR group cries, $t(10) = 2.14$, $P = 0.058$ (Cohen's $d = 1.25$). Groups did not differ on measures of phonation in pain-related cries.

Follow-up tests on mean F_0 and range of F_0 were conducted excluding the infants later classified with ASD. Differences between the AR and LR infants remained significant for F_0 , $t(9) = 2.48$, $P = 0.035$, and marginally significant for F_0 -range, $t(9) = 1.86$, $P = 0.096$ (two-tailed). Follow-up tests of differences in other variables revealed a trend for pain-related cries with a smaller range of amplitude in the AR than the LR group, $t(10) = 2.02$, $P = 0.070$. There were no significant differences between AR and LR groups on the acoustic features of the non-pain-related cries.

Subject Level Analyses

Two of the three AR infants with 36-month classifications of ASD had vocalizations that could be analyzed, one with a pain-related cry and one a non-pain-related cry. For pain-related cries, the ASD case had the second highest pitch in the sample (higher than all LR children). For non-pain-related cries, the other confirmed ASD case had the third highest pitch range estimate in the overall sample. Other variables were also explored on an individual basis, and it was found that the two infants with later ASD diagnoses had cries with the lowest average phonation in each of the pain-related and non-pain-related groups of cries. These individual level data are depicted in Figure 1.

Follow-up Analyses

Follow-up analyses were run to address potential confounding factors. We examined the position that each baby was in during the cry episode. For non-pain cries, most infants were either being held or in a supported sitting position (7/10 AR, 6/6 LR infants). The three other AR infants were on their stomachs. Similarly, during pain-related cries, 6/7 AR and 3/5 LR infants were either being held or in a supported sitting position. The other AR infant and the two other LR infants were on their stomachs. Finally, the AR group had a somewhat higher proportion of girls than the LR group, although not statistically different ($\chi^2 = 1.06$). However, boys did not differ from girls in F_0 (451.2 vs. 478.3, boys vs. girls), range of F_0 (110.8 vs. 105.5), or phonation (45% vs. 51%).

Discussion

We investigated the acoustic properties of infant cries observed in 6-month-old infants at risk for autism and a comparison sample of infants not at risk for autism. Infants at risk for autism, as a group, produced pain-related cries with higher and more variable pitch than infants not at risk for autism. The finding of elevated pitch in the AR group appeared to be influenced but not fully explained by the one at-risk infant later identified with autism at age 3 that produced a pain-related cry. This infant's cry had particularly high pitch relative to both groups of infants, but the at-risk group as a whole produced pain-related cries with higher pitch and greater variability in pitch than LR infants. A different picture emerged for non-pain-related cries. Here, there were no differences between groups on any acoustic cry parameters. However, the at-risk infant with a later diagnosis of autism did produce a cry that was elevated in pitch range relative to infants in both the at-risk and no-risk groups. For the LR babies, F_0 values were generally within what is expected to be a typical range for infant cries in the birth through 1-month period [Lester et al., 2002; Michelsson, Eklund, Leppanen, & Lyytinen, 2002; Rothganger, 2003], and for pain cries of babies up to 7 months

of age [Wasz-Hockert et al., 1968]. Mean F_0 of pain cries in the AR infants was significantly higher than the LR group and toward the upper range of these historical samples cited earlier.

An additional a priori hypothesis was that infants at risk for autism would produce cries with more dysphonation than LR infants. Group analyses did not reveal significant differences on this measure for either pain- or non-pain-related cries. However, analysis of individual subject-level data revealed that the two infants later diagnosed with ASD did produce poorly phonated cries relative to other infants. An additional finding was that the infants at risk for autism produced pain-related cries with a somewhat smaller range of amplitude than the LR infants. This finding is interpreted with caution in part because it was found on post-hoc analyses and also because the measurement of cry amplitude may be affected by aspects of the recording method that are difficult to control. Nonetheless, this finding is intriguing and suggests that vocal control or regulation of the force of vocalizations may be affected in infants at risk for autism. Formants (F_1 and F_2) were also examined in post-hoc analyses. These were not found to differentiate groups, and this may in part be due to the difficulties in estimating formant frequencies in infant vocalizations as compared with adult speech. However, they are included here in order to provide some basis for comparison with future research.

These findings provide preliminary evidence for differences in cry production in infants at risk for autism, including those who later receive a diagnosis of an ASD. Nonetheless, several important limitations are noted. First, while this study did not utilize standard methods to elicit cries [LaGasse et al., 2005], cries were coded after the fact to determine whether they were more or less likely to be pain-related. It is likely that the resulting variability in the precipitants of cry resulted in variability in the acoustic features measured. In particular, this may have limited our power to detect group differences in cries that were not coded as pain-related, where there was likely to have been a greater variability in the causes of cry than in samples reliably identified as pain-related. Alternatively, pain-related cries may be a more sensitive measure of autism-related differences in cry production than non-pain-related cries. It may be necessary to challenge or stress the neurobiological system of the infant in order to reliably observe differences in the control over vocal production. This supports the idea that detection of risk for autism in infancy may be difficult because these signs will be observable only under certain conditions.

One implication of this study is that standard cry elicitation procedures may reduce error variance associated with naturalistic observation and may therefore increase the sensitivity to detect alterations in crying related to ASD. In addition, because acoustic properties of cries are affected by the intensity of stimuli [Lehr et al., 2007; Porter, Porges, & Marshall, 1988], variations in acoustic properties of cries in relation to varying intensity of stimuli may offer information on the development of arousal and regulation in ASD and other clinical groups. We should also note that analysis of non-pain cries can have value in relation to the study of ASD in infancy. Crying is a component of the early developing dyadic relationship in infants and caregivers [Lester, 1984], and crying is a universal human vocalization that elicits behavioral and physiologic responses in caregivers [Newman, 2007]. A developmental understanding of different types of crying in relation to infant-caregiver interactions in infants at risk for or later diagnosed with ASD would enhance our understanding of the emergence of early social and communicative features in this group of disorders.

An additional limitation to this study is that the measurement of developmental functioning at outcome resulted in some missing data on the measure of developmental functioning in the sample. Specifically, there was missing data for Mullen scale scores for three children in

the cohort. These missing data prevent a full characterization of the children who did and did not have a later diagnosis of ASD. Future research would benefit from a more detailed description of developmental outcomes, including relevant aspects of linguistic functioning. This would allow for an estimation of whether atypical cry acoustics is seen across the population of children with autism or perhaps in a subgroup of children with specific outcomes. For example, it would be of value to know whether differences in infant crying would be more likely to be seen in individuals with more severe and impairing forms of autism. Other information on children such as birth weight and other growth variables would also be of potential value to future research in this area but were not available for this study.

A third limitation of this study is that there are additional acoustic measures that may provide more specific information on the cry characteristics of infants at risk for ASD. The focus here was on measures that have been the focus of other research on at-risk and clinical populations, including F_0 and phonation. Some past research has examined other ways to characterize F_0 , including jitter [Grauel, Höck, & Rothgänger, 1990], spectral tilt [Goberman & Robb, 1999], and spectral intensity [Zeskind, Parker-Price, & Barr, 1993]. Our focus on broad measures of F_0 and phonation is supportive of the hypothesis that aspects of early cry production may be affected in infants at risk for autism. Future research should include additional measures of acoustic cry characteristics. One issue here is that there is a trade-off between automated analyses and more labor-intensive manual analyses. There is a need for new analysis tools that can yield information on multiple levels of analysis for infant cries.

The size and composition of the study sample also has bearing on the interpretation of our results. While significant differences were found between groups for pain-related cries, the null finding for non-pain-related cries may have been related to low power based on small sample size. However, we observed a large variation in the pitch of the non-pain-related cries, underscoring the point that variability in these cries limited statistical power. An interesting alternative interpretation is that non-pain-related cries were more difficult to attribute to any one precipitant or cause. This is important in the context of past research on emotional and vocal communication in children with autism, which has found that vocalizations of children with autism are more likely to be atypical in quality [Sheinkopf et al., 2000; Wetherby et al., 1989] and have less clear communicative value than nonautistic children [Ricks & Wing, 1975]. An additional aspect of this sample that should be noted is that there were more girls in the sample than boys. This was the function of sampling in early infancy prior to knowledge of diagnostic outcome. Our analyses indicated that gender was not a confounding factor in our analyses.

It would be interesting to consider the communicative value and parental perception and interpretation of infant cries in this population. Thus, in addition to acoustic analyses, future research should include measures of adult perception of infant cries. As an example of such an analysis, Esposito and Venuti [2009] reported that cries of 12-month-old infants later diagnosed with autism elicited different kinds of maternal responses than did the cries of typically developing infants. This type of analysis is certainly consistent with a biosocial model of infant crying [Lester, 1984]. In this way, infant cries can be viewed both as an aspect of vocal production and as a component of the infant's developing system of communication that could affect the developing parent–infant relationship. This decidedly transactional view has important implications for research on early vocal development in autism.

Indeed, autism is an interesting case for this biosocial model of infant crying. On the one hand, atypical cry acoustics in this population can be expected to be a nonspecific indicator of disturbance in central systems that influence cry production. Thus, atypical cry acoustics,

if replicated in this population, may serve as a positive symptom that, when combined with other indices of risk, may have additional value as a means to increase the accuracy of early identification efforts [Sheinkopf et al., 2000]. Drawing an analogy to diagnostic practice in early childhood, atypical cries may be a nonspecific risk indicator that can be combined with other clinical information (e.g. family history, subsequent development course, etc.) or used with certain subpopulations (e.g. infant siblings) to determine risk for ASD.

On the other hand, disruptions in cry production may in part be an early manifestation of disrupted communication that is such a prominent feature of autism. Differences in cries associated with autism may be an early manifestation of disrupted affective presentation and may play a role in the development of poor social communication in this population. Thus, understanding developmental processes of dyadic interaction, including infant emotional signaling and parental perception and responses to these signals, may yield insights into the processes involved in the developmental progression and emergence of autistic symptoms with age.

Finally, while some research has identified differences in very subtle aspects of social responses in infants at risk for autism [e.g. Cassel et al., 2007], other research has indicated that social and communicative differences emerge with development over the course of the second 6 months of life [Ozonoff et al., 2010]. Whether atypical aspects of cry production are found to differentiate infants at risk for autism is of course an empirical question, and these preliminary results require careful replication. Nonetheless, the results of this study suggest that the identification of very early indicators of risk for autism may include neurobehavioral characteristics not traditionally linked to the core set of social communication deficits seen later in the development of children with ASDs.

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Figure 1. Individual data for fundamental frequency (A), range of fundamental frequency (B), and percentage of phonated blocks (C) by cry type and risk group (individuals with 36-month classification of autism spectrum disorder (ASD) are noted).

Outcome Data for Autism Spectrum Disorder (ASD)-Risk Infants, Including Mullen Scale of Early Learning (MSEL), MacArthur Communicative Development Inventories, and Diagnostic Classification

Table 1

Case	Diagnostic classification	MSEL visual reception ^a	MSEL receptive language ^a	MSEL expressive language ^a	MSEL composite ^b	MacArthur CDI (percentile)
1		38	35	49	77	< 1
2		70	49	38	97	< 1
3		54	49	52	109	< 1
4	ASD	<i>m</i>	<i>m</i>	20	<i>m</i>	< 1
5		48	44	52	103	5
6		56	49	<i>m</i>	<i>m</i>	5
7		45	41	54	101	15
8		63	53	65	124	15
9	ASD	20	20	36	54	20
10	ASD	<i>m</i>	<i>m</i>	<i>m</i>	<i>m</i>	20
11		40	51	56	96	25
12		56	53	<i>m</i>	78	35
13		52	53	54	100	50
14		70	58	56	105	50
15		45	56	58	107	50
16		60	75	78	141	65
17		54	53	45	100	75
18		67	58	63	117	90
19		45	63	76	127	90
20		63	49	43	111	<i>m</i>

Note. One additional ASD-risk baby had cry data available at 6 months of age but was lost to follow up at the 36-month visit. Missing data on the MSEL was due to administration errors.

^aMSEL *t*-scores.

^bMSEL standard scores.

m, data missing.

Table 2**Variables Produced by Acoustic Analysis**

Pitch (F_0)	Average pitch of cry (Hz)
Variability of pitch	Range of F_0 across the cry episode
Phonation	Mean percent of 25-msec blocks with voiced mode
Hyperphonation	Mean percent of 25-msec blocks with $F_0 > 1,000$ Hz
Utterance duration	Average time of utterances (sec)
Average energy/amplitude	Loudness of cry (mean dB)
Variability of energy/amplitude	Range of cry amplitude
First Formant (F_1)	First resonant frequency (Hz)
Second Formant (F_2)	Second resonant frequency (Hz)

Table 3

Acoustic Characteristics of Cries Produced by ASD-Risk and Low-Risk Infants

Pain-related cries	ASD-risk (<i>n</i> = 7)		Low-risk (<i>n</i> = 5)		<i>P</i> (two-tailed)	<i> d </i>
	Mean	SD	Mean	SD		
Fundamental frequency (<i>F</i> ₀)	504.87	57.42	420.28	40.32	0.02	1.65
Variability of <i>F</i> ₀	129.47	60.12	67.23	27.43	0.06	1.25
Phonation (%)	51.65	14.61	48.86	13.72	0.75	0.20
Hyperphonation (%)	7.36	9.61	0.00	–	#	–
Utterance duration	5.00	1.25	6.61	4.48	0.38	0.54
Average energy/amplitude	6435.95	672.81	5985.89	748.34	0.30	0.64
Variability of energy/amplitude	2759.83	963.14	4007.64	1173.53	0.07	1.19
First formant (<i>F</i> ₁)	1171.40	170.40	1017.36	234.93	0.22	0.78
Second formant (<i>F</i> ₂)	3593.16	125.56	3672.51	98.38	0.27	0.69

Non-pain-related cries	ASD-risk (<i>n</i> = 10)		Low-risk (<i>n</i> = 6)		<i>P</i> (two-tailed)	<i> d </i>
	Mean	SD	Mean	SD		
Fundamental frequency (<i>F</i> ₀)	465.00	44.04	474.50	84.89	0.82	0.15
Variability of <i>F</i> ₀	114.77	55.94	115.78	68.48	0.98	0.02
Phonation (%)	48.54	15.83	45.25	8.53	0.65	0.24
Hyperphonation (%)	1.32	3.64	4.78	8.67	0.39 ^a	0.58
Utterance duration	3.91	2.48	4.07	1.15	0.88	0.08
Average energy/amplitude	5728.78	1099.14	5701.89	491.95	0.95 ^a	0.03
Variability of energy/amplitude	3534.35	910.81	4044.89	864.89	0.29	0.57
First formant (<i>F</i> ₁)	1168.28	187.73	1120.50	208.76	0.64	0.24
Second formant (<i>F</i> ₂)	3816.50	307.12	3782.89	139.24	0.81	0.13

[#]Test not interpreted because of zero value in comparison group.^aTest adjusted for unequal variances.

ASD, autism spectrum disorder; SD, standard deviation.