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ACOUSTIC ANALYSIS OF ORAL PRODUCTIONS OF INFANTS LATER DIAGNOSED WITH AUTISM AND THEIR MOTHER

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ABSTRACT: Research on early signs of autism in social interactions often focuses on infants' motor behaviors; few studies have focused on speech characteristics. This study examines infant-directed speech of mothers of infants later diagnosed with autism (LDA; $n = 12$) or of typically developing infants (TD; $n = 11$) as well as infants' productions (13 LDA, 13 TD). Since LDA infants appear to behave differently in the first months of life, it can affect the functioning of dyadic interactions, especially the first vocal productions, sensitive to expressiveness and emotions sharing. We assumed that in the first 6 months of life, prosodic characteristics (mean duration, mean pitch, and intonative contour types) will be different in dyads with autism. We extracted infants' and mothers' vocal productions from family home movies and analyzed the mean duration and pitch as well as the pitch contours in interactive episodes. Results show that mothers of LDA infants use relatively shorter productions as compared to mothers talking to TD infants. LDA infants' productions are not different in duration or pitch, but they use less complex modulated productions (i.e., those with more than two melodic modulations) than do TD. Further studies should focus on developmental profiles in the first year, analyzing prosody monthly.

RESUMEN: La investigación sobre las tempranas señales de autismo en interacciones sociales a menudo se enfoca en la conducta motora de los infantes; pocos estudios se han enfocado en las características del habla. Este estudio examina el habla dirigida a los infantes de madres cuyos infantes son diagnosticados con autismo posteriormente (LDA, n = 12) o de infantes que se desarrollan típicamente (TD, n = 11), así como las producciones de los infantes (13 LDA y 13 TD). El hecho de que los infantes LDA parecen comportarse diferentemente en su primer mes de vida puede afectar el funcionamiento de las interacciones diádicas, especialmente las primeras producciones vocales, sensibles a la expresividad y a compartir emociones. Asumimos que en los primeros seis meses de vida, las características prosódicas (promedio de duración, promedio de entonación y tipos de curvas de entonación) serán diferentes en díadas con autismo. Obtuvimos producciones vocales de los infantes y madres en vídeos caseros y analizamos el promedio de duración y entonación, así como las curvas de entonación en episodios interactivos. Los resultados muestran que las madres de infantes LDA usan producciones relativamente más cortas comparadas con las madres que le hablan a infantes del grupo TD. Las producciones de los infantes LDA no son diferentes en duración o entonación, pero ellos usan producciones moduladas (las que tienen más de dos modulaciones melódicas) menos complejas que las de los infantes con desarrollo típico. Estudios posteriores deben enfocarse en perfiles de desarrollo en el primer año, analizando cada mes la prosodia.

RÉSUMÉ: La recherche sur les signes précoces d'autisme dans les interactions sociales met souvent l'accent sur les comportements moteurs des nourrissons. Peu d'études mettent l'accent sur les caractéristiques vocales. Cette étude examine les paroles dirigées vers le nourrisson des mères de bébés plus tard diagnostiqués avec un autisme (abrégés selon l'anglais LDA, n = 12) ou d'un bébé se développant de manière typique (abrégés selon

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l'anglais TD, n = 11), ainsi que les productions des nourrissons (13 LDA et 13 TD). Puisque les bébés LDA semblent se comporter différemment dans les premiers mois de leur vie, cela peut affecter le fonctionnement d'interactions dyadiques, surtout les premières productions vocales, la partage d'émotions et la sensibilité à l'expression. Nous supposons que dans les six premiers mois de la vie les caractéristiques prosodiques (durée moyenne, hauteur moyenne de la voix, types de contour de l'intonation) sont différentes chez les dyades avec un autisme. Nous avons extrait les productions vocales de bébés et de mères dans des vidéos familiales et analysé la durée moyenne et la voix moyenne, ainsi que les contours de voix dans des épisodes d'interaction. Les résultats montrent que les mères de bébés LDA utilisent des productions relativement plus courtes que ne le font les mères parlant à des bébés TD. Les productions de bébés LDA n'étaient différentes ni en durée ni en voix mais utilisaient des productions modulées moins complexes (pour ce qui concerne ceux qui faisaient état de plus de deux modulations mélodiques) que les bébés se développant de manière typique. Plus d'études devraient se pencher sur les profils de développement dans la première année, en analysant la prosodie mensuellement.

ZUSAMMENFASSUNG: Forschung über frühe Anzeichen von Autismus in sozialen Interaktionen fokussiert oft auf motorische Verhaltensweisen von Säuglingen, nur wenige Studien legten den Fokus auf Sprachmerkmale. Diese Studie untersucht die an den Säugling gerichtete Sprache der Mütter von Säuglingen mit später diagnostiziertem Autismus (LDA (later diagnosed with autism), n = 12) oder von normal entwickelten Säuglingen (TD (typically developing), n = 11) sowie die stimmlichen Produktionen der Säuglinge (13 LDA und 13 TD). LDA-Säuglinge scheinen sich im ersten Lebensmonat anders zu verhalten. Dieses Verhalten kann dyadische Interaktionen beeinflussen, vor allem die ersten stimmlichen Produktionen, die mit Ausdrucksfähigkeit und geteilten Emotionen zusammenhängen. Wir gehen davon aus, dass in den ersten sechs Lebensmonaten prosodische Merkmale (mittlere Dauer, mittlere Tonhöhe und Tonhöhenkonturen) in Dyaden mit Autismus anders sein werden. Wir extrahierten stimmliche Produktionen von Säuglingen und Müttern aus Familienvideos und analysierten die mittlere Dauer, Tonhöhe und die Tonhöhenkonturen anhand interaktiver Episoden. Die Ergebnisse zeigen, dass Mütter von LDA-Säuglingen vergleichsweise kürzere Produktionen verwenden als Mütter die zu ihren TD-Säuglingen sprechen. Produktionen von LDA-Säuglingen unterscheiden sich nicht in Dauer oder Tonhöhe, aber sie verwenden weniger komplex modulierte Produktionen (mit mehr als zwei melodischen Modulationen) als normal entwickelte Säuglingen. Weitere Studien sollten auf die Entwicklungsprofile im ersten Jahr fokussieren und dabei die Prosodie monatlich analysieren.

ABSTRACT: Research on early signs of autism in social interactions often focuses on infants' motor behaviors; few studies focused on speech characteristics. This study examines infant-directed speech of mothers of infants later diagnosed with autism (LDA, n = 12) or of typically developing infant (TD, n = 11), as well as infants' productions (13 LDA and 13 TD).
抄録:社会的な相互交流における自閉症の早期兆候についての研究は、しばしば乳児の運動行動に焦点付けられていた。会話の特徴に焦点付けた研究はほとんどない。この研究は、後に自閉症と診断された乳児(LDA, n = 12)または典型的に発達している乳児(TD, n = 11)の母親が子どもに向ける会話、ならびに乳児の言葉の産出(13 LDA and 13 TD)を調査した。LADの乳児は生後最初の1か月に異なる行動をするので、それは二者の相互交流機能、特に表出性と情緒の共有に敏感な、最初の音声の産出に、影響しかねない。私たちは、生後6か月の間に、韻律的な特性prosodic characteristics(平均持続時間、ピッチの平均と、イントネーションの輪郭のタイプ)は、自閉症児のペアでは異なるだろうと、仮定する。私たちは、家族の過程ビデオから、乳児と母親の音声の産出を抽出し、相互交流エピソード中の平均持続時間とピッチ、そしてピッチの輪郭を分析した。結果から、LDA乳児の母親は、TD乳児に話しかけている母親に比べて、相対的に短い産出時間を用いていることがわかった。LDAの乳児の産出は、典型的に育っている乳児と比べて、持続時間やピッチは変わらなかったが、複雑な変調のある産出(二つ以上のメロディの変調を伴うもの)を使うことが少なかった。今後の研究は、韻律prosodyを毎月分析して、最初の1年の発達プロファイルに焦点付けるべきである。

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Autism is characterized in international classifications according to the *Diagnostic and Statistical Manual of Mental Disorders, fourth edition, text revision*[1] (*DSM-IV-TR*; American Psychiatric Association, 2000) and the International Classification of Diseases, 10th edition (World Health Organization, 1994) by severe and pervasive impairments in the development of reciprocal social interaction, verbal and nonverbal communication skills, and stereotyped patterns of behaviors and interests. Symptoms are meant to appear before the age of 3 years. Studies have examined the early development of infants later diagnosed with autism (LDA), focusing on the first 2 years of life. Several studies have shown that early behavioral difficulties with socialization, reciprocal interactions, and attention are common early on (Adrien, Faure et al., 1991; Adrien et al., 1993; Adrien, Perrot, Hameury et al., 1991; Adrien, Perrot, Sauvage et al., 1991; Maestro et al., 2005; Maestro et al., 2002; Osterling & Dawson, 1994; Osterling, Dawson, & Munson, 2002; Wetherby, Watt, Morgan, & Shumway, 2007; White, Koenig, & Scahill, 2007).

Despite meticulous behavioral observations giving us substantial information about the development of very young children with autism and the consequent literature concerning language in autism (e.g., Howlin, 2003; Tager-Flusberg & Calkins, 1990), research about prosodic abilities is still fragmented (McCann & Peppé, 2003; Shriberg et al., 2001), and those about language development within the first 6 months of life are extremely rare. We only found two recent studies about the second and third years (Paul, Chawarska, Cicchetti, & Volkmar, 2008; Schoen, Paul, &

[1]The *DSM-IV-TR* was in use when the authors carried out the study. With the new *DSM-V*, professionals talk about autism spectrum disorders (which include social the communication domain and restrictive interests and the repetitive behaviors domain).

Chawarska, 2011). During the first year of life, it has been shown that LDA infants' vocalizations are poor; that is, they are less frequent or shorter in duration (Adrien et al., 1993; Cohen et al., 2013; Dawson, Osterling, Meltzoff, & Kuhl, 2000). These results do not take into account the prosodic characteristics of vocal productions: mean pitch, rhythm, or intonation. Few studies have focused specifically on the prosodic characteristics of these infants' productions. The current study aims to analyze infants' vocal productions during interactive situations as well as their mothers' vocal productions.

PROSODY AND CHILDREN WITH AUTISM

Prosody is the study of aspects of speech that typically apply to a level above that of the individual phoneme. It represents a very important stage in language acquisition and is commonly called "tone of voice" (Cutler & Swinney, 1987; Demuth, 1995; D'Odorico, Fasolo, & Marchione, 2009; Höhle, Bijeljac-Babic, Herold, Weissenbornd, & Nazzi, 2009; Prieto, Estrella, Thorson, & Del Mar Vanrell, 2011). At the phonetic level, prosody is characterized by vocal pitch (fundamental frequency), loudness (acoustic intensity), and rhythm (phoneme and syllable duration).

Because of the lack of studies on infants' prosody in the autism field and to better understand what should be looked at in infants' prosody, it seems important to examine studies that have been carried out with children with autism. People with autism are considered as having a monotonous and even abnormal prosody. According to Ricks (1979), vocal productions of children with autism (3–6 years of age) present prosodic particularities. He showed that parents with typical infants do not recognize productions of their own infants among vocal productions of typical and autistic babies whereas parents of an LDA child were able to identify productions of their own infant among others. Typical infants probably use a similar range of productions to express themselves, contrary to young children with autism who have an atypical and idiosyncratic way of speaking that can be easily recognized. Later, Baltaxe, Simmons, and Zee (1984) showed that children with autism (4–12 years of age) were less inclined to use the prosodic frequency range normally used by typical children.

Older children with autism were able to do two types of intonation (declarative or interrogative forms) in an imitation task, but they could not use these intonations when reading pairs of sentences which differed only by punctuation (Fosnot & Jun, 1999). Children with pervasive developmental disorders also have difficulty, as compared to other teenagers who are the same age, such as the correct pronunciation of words or emphasizing the right syllables or element of a sentence (Paul, Augustyn, Klin, & Volkmar, 2005). There is therefore much information that they cannot communicate to others, as typical teenagers do. Finally, Warren et al. (2010) showed that children (16–48 months of age) with autism emitted 29% fewer vocalizations in daily situations than do typical children. Conversations engaged by autistic children are less frequent and are shorter than are those of typical children. In addition, young autistic children's vocalizations are rarely followed by an adult's response. Their vocal productions are like "monologues" which do not seem to involve partner communication.

Because we know parents usually adopt a specific prosody when talking to their infant (e.g., Fernald & Simon, 1984; Kitamura & Burnham, 2003; Smith & Trainor, 2008), these studies leave open the question of whether parents react differently when facing an infant who vocalizes in an atypical way, with no explicit conversational purpose. In other words, the particular speech of LDA infants may influence the parents' behaviors and initiatives as the infants strive to establish contact with them. To assess whether this is the case, we believe it is vital to explore the adults' as well as the infants' vocal productions.

PROSODY OF MOTHERS' VOCAL PRODUCTIONS TO CHILDREN WITH AUTISM

From birth and sometimes before (through the womb), parents speak to their infant. To do so, they use a specific language called *infant-directed speech* (IDS; Fernald & Simon, 1984; Garnica, 1977; Stern, Spieker, Barnett, & MacKain, 1983; Stern, Spieker, & Mackain, 1982). Adults' vocal productions refer to all verbal outputs containing words, onomatopoeia, or vocal imitations of their child (Bloom, 1988; Fagan & Iverson, 2007; Hsu, Fogel, & Messinger, 2001). Danon-Boileau (2007) analyzed productions of a mother talking to her LDA infant or to her typically developing infant. He noted that the productions showed higher intensity and more melodic modulations with the LDA infant. The mother also tended to finish her vocalizations by rising contours, which might be to draw the infant's attention. However, Laznick (2007) depicted mothers' prosody as more monotonous and with fewer modulations when talking to an LDA infant. Trevarthen and Daniel (2005) observed a father interacting with his 11-month-old twins, one of them having an autistic syndrome. They described the father's voice as warmer and smoother with the typically developing twin. His speech flow had more rhythm, with long breaks to give her time to answer. These case studies highlight the importance of introducing a linguistic dimension to the question of early signs of autism. We have to go further by doing a group comparison.

To our knowledge, there are very few studies on mothers' prosody when talking to their LDA infant, apart from these few case studies. There are even fewer studies combining infant and mother prosody. The aim of this study therefore is to highlight the specificity of prosodic characteristics of infants with autism and of their mothers. We will carry out prosodic analyses from verbal and vocal productions extracted from family home movies.

HYPOTHESES

Previous studies have shown an expressionless tone of voice and a lack of knowledge on how to use prosody in everyday life in people with autism; that is, a difficulty to manipulate prosodic modulations, changes in register, and stress usually used to mark

the speaker's general feeling state and to highlight the structure to insist on a specific part of the utterance (Bonneh, Levanon, Dean-Pardo, Lossos, & Adini, 2011; Grossman, Bemis, Skwerer, & Tager-Flusberg, 2010; Paul et al., 2005; Shriberg et al., 2001). It is worthwhile to examine whether these atypical tone characteristics can be detected in LDA infants (<6 months of age). The aim of this study is to examine prosodic differences between vocal productions of LDA infants and TD infants. We assume that the prosodic properties of the vocal productions of LDA infants will be more monotonous from those of TD infants (lower mean pitch, flatter pitch contour, shorter duration).

Moreover, we want to show specific differences in prosody in mothers' speech to their LDA infant. The infant is an active partner in daily spontaneous exchanges with his or her mother (Bateson, 1975; Stern, 1985). The infant's behavior and responsiveness will impact the mother's behavior. We assume that mothers will adapt the way that they talk to their infant to capture or keep the infant's attention. We predict mothers' prosody will be different whether they talk to an LDA infant or to a TD infant. Mothers of an LDA infant should display higher mean pitch and shorter duration of utterances because they will try to grab or maintain the infant's attention by calling him or her or by playing peek-a-boo.

STUDY 1: INFANTS' UTTERANCES

Method

Ethics. This study has been approved by a French ethical comity (people protection comity in Paris).

Participants. The present study is retrospective and is based on family home-video analysis. The population consists of children and teenagers whose parents agreed to lend their family home movies for the study. These videos were made by parents when their child was younger (<6 months old) and not yet diagnosed with autism for those who later received that diagnosis. Videos from 13 infants (11 boys, 2 girls) later diagnosed with autism (LDA) and 13 infants (9 boys, 4 girls) with typical development (TD) were analyzed. Four additional LDA infants were excluded because there were less than 10 vocalizations to analyze. Children on the videotapes are between 0 and 6 months old (LDA: M age = 4.38, SD = 0.88; TD: M age = 3.71, SD = 1.39). There is no significant difference for the age, $t(24) = 1.49$, $p = .149$, between-groups, or gender ratio, Fisher's exact test for frequency data: $p = .678$. Mean age of first developmental assessment for LDA infants is 5.2 (SD = 2.1) years.

Families of LDA infants were recruited from psychologists' offices in Paris on the occasion of the psychological assessment. Diagnosis of autism was made by a multidisciplinary team specializing in autism. They used *DSM-IV-TR* criteria and the Childhood Autism Rating Scale (Schopler, Reichler, & Renner, 1988). Psychological assessment was made with the appropriate French tests. A description of key characteristics of the LDA sample is shown in Table 1. Heterogeneity of the sample corresponds to the variability that clinicians usually deal with in their practice. TD infants were recruited within the researchers' families and social circles. No member of their family had been diagnosed with autism. No assessment was made, but researchers made sure that the infants when older were registered in a normal school curriculum and displayed no sign of autism. This difference in the way participants have been recruited could be a bias; however, it seems that our participants were approximately from the same social class. Indeed, people living in large cities, with access to video cameras more than 10 years ago and who are aware of the importance of participating in such research, are often from upper socioeconomic classes.

The age period observed on family home movies was 0 to 6 months of age. Only the soundtrack was analyzed. All the infants' productions were extracted. To be selected, an audio sequence had to correspond to an interactive situation between the infant and his or her mother. Audible and analyzable videos were selected—without any background noise (television, musical game, hand clapping, etc.), but a speaker must be close enough to be heard. Vocal production boundaries were determined by an audible breath or a silence (Lynch, Oller, Steffens, & Buder, 1995). Vegetative sounds were excluded. A description of selected sequences for each participant is shown in Table 2.

Analyses. For each infant, every audible vocal production was selected (M duration = 707.95 ms, SD = 527.51 ms, range = 78–3,810 ms). Vocal production is a signal that can be broken down into frequency, time, and amplitude. In this study, the prosodic analysis will refer to productions' duration (in ms), mean pitch (M of fundamental frequency = $F_0\mu$), and pitch contours. We decided not to assess vocal productions' intensity (number of decibels produced) because it would have required that participants wear a microphone at a constant distance to be confident that the variations were linked to the vocal productions themselves and not to the changing distance between the microphone and the mouth.

Four pitch contour classes characterize the utterances' melody. Intonation contours of mothers' and infants' productions were classified by shape using the categories used by Gratier and Devouche (2011), which allow assessment of prosodic modulations and to determine the variability among participants in this study. The four classes are simple contour (rising: R, falling: F, flat: Fl), one-inflection contour (rising-falling: RF or falling-rising: FR), two-inflections contour (RFR or FRF), and complex contour with more than two inflections (e.g., RFRF, FRFR, etc.).

For contours on a pitch range higher than 300 Hz, a difference of 50 Hz between two peaks is needed to be considered as rising or falling; otherwise, it is considered as flat. When the utterance is on a pitch range lower than 300 Hz, a difference of 30 Hz is needed (for examples, see Figures 1 and 3). This method has been chosen because of the logarithmic scale of the sound and the specificities of human hearing abilities. Utterances were analyzed with Praat (Boersma & Weenink, 2007), free software that enables phonetic analyses and transcription (Figure 1). The characteristics that we have taken into account allow us to draw up the prosodic profile of the infants. We therefore can highlight the differences linked to autism.

TABLE 1. *Description of LDA Population Characteristics*

Participant	CARS Score	*M* Age at First Assessment (months)	Developmental Age (first assessment) (months)	Estimated Age of First Symptoms (months)	DQ	DQ Measurement Instrument	Language Acquisition
LDA1	39	92	54	9	59	EDEI-R	Yes
LDA2	36	55	44	12	80	EDEI-R	Yes
LDA3	50	50	24	6	48	PEP-R	Yes
LDA4	46.5	71	17	5	25	BL-R	No
LDA5	35	30	20	12	67	BL-R	Yes
LDA6	37	89	58	12	65	PEP-R	Yes
LDA7	35	36	27	12	75	BL-R	Yes
LDA8	40	66	30	5	45	EDEI-R	Yes
LDA9	37	50	38	18	76	PEP-R	Yes
LDA10	42	33	11	2	30	BL-R	No
LDA11	47	118	33	5	28	EDEI-R	No
LDA12	39	50	42	12	84	PEP-R	Yes
LDA13	36	72	56	24	78	PEP-R	Yes

LDA = infants later diagnosed with autism; DQ = developmental quotient; EDEI-R = "échelles différentielles d'efficience intellectuelle-révisées:" differential scales of intellectual efficiency-revised (Perron-Borelli, 1997); BL-R = Brunet-Lézine-Revised (Josse, 2001); PEP-R = Psychoeducational Profile-Revised (Schopler, 1997).

TABLE 2. *Description for Each Participant of Gender (M = Male, F = Female), Current Age at the Beginning of the Study, Age of Which Movies are Available (in bold, those selected of available movies), Total Length of Movies, Total Number of Movies, and Mean Age on Selected Videos*

			Movies (age in months)									
Participant	Gender	Current Age	0	1	2	3	4	5	6	Total Duration	No. of Movies	*M* Age on Selected Movies
LDA1	M	18.4	X	X	X	**X**	**X**	X		00:17:12	16	3.5
LDA2	M	14.4		X	X	**X**	**X**	**X**	**X**	01:37:25	62	4.5
LDA3	F	13.2	X	**X**	X	X	**X**	X	**X**	03:01:39	19	3.7
LDA4	M	15.2			X	**X**	**X**	X	X	01:03:54	47	4.0
LDA5	M	24.2					**X**	X		00:10:39	8	4.5
LDA6	M	14.5				**X**	**X**	X	**X**	02:10:44	53	4.3
LDA7	M	21.2					**X**		**X**	00:24:15	3	6.0
LDA8	M	15.7				X			**X**	00:17:37	2	6.0
LDA9	F	14.0						**X**		00:25:12	2	5.0
LDA10	M	20.7					**X**			00:10:44	1	4.0
LDA11	M	26.0	X	**X**	**X**	**X**	**X**	**X**		01:15:00	1	3.0
LDA12	M	18.5					**X**		X	00:14:19	2	4.0
LDA13	M	20.6				**X**	**X**	**X**	X	01:26:45	25	4.5
TD1	F	12.4						**X**	X	00:28:59	2	5.0
TD2	M	8.7	X	**X**	**X**	**X**	**X**	**X**	**X**	06:12:29	81	3.5
TD3	M	6.8	X	**X**	X	X				00:33:22	14	1.0
TD4	M	14.0						**X**		00:09:13	3	3.0
TD5	F	6.10				**X**				00:05:59	4	2.0
TD6	M	7.3			**X**			X	**X**	00:05:21	6	4.0
TD7	F	6.1	X	**X**	**X**	**X**	**X**	**X**	**X**	00:58:49	54	3.5
TD8	M	13.11	X	**X**	X	**X**				00:10:52	16	2.0
TD9	M	17.2						**X**	X	00:13:30	2	5.0
TD10	F	9.2						**X**	**X**	00:11:02	4	5.5
TD11	M	16.3					**X**	X	X	00:15:01	4	4.0
TD12	M	17.0				**X**	X	**X**	**X**	00:25:06	8	4.7
TD13	M	10.9						**X**	X	00:05:30	3	5.0

Results

Interrater reliability. Two raters were not aware of diagnosis. They evaluated all of the utterances once. They agreed on the nonanalyzable utterances that were rejected due to, for example, crying, shouting, or bad sound quality. Productions considered as nonspeech productions such as distress productions (e.g., cries, whines, fusses) or delight productions (e.g., laughter) were excluded from the prosodic analysis (Sheinkopf, Mundy, Oller, &

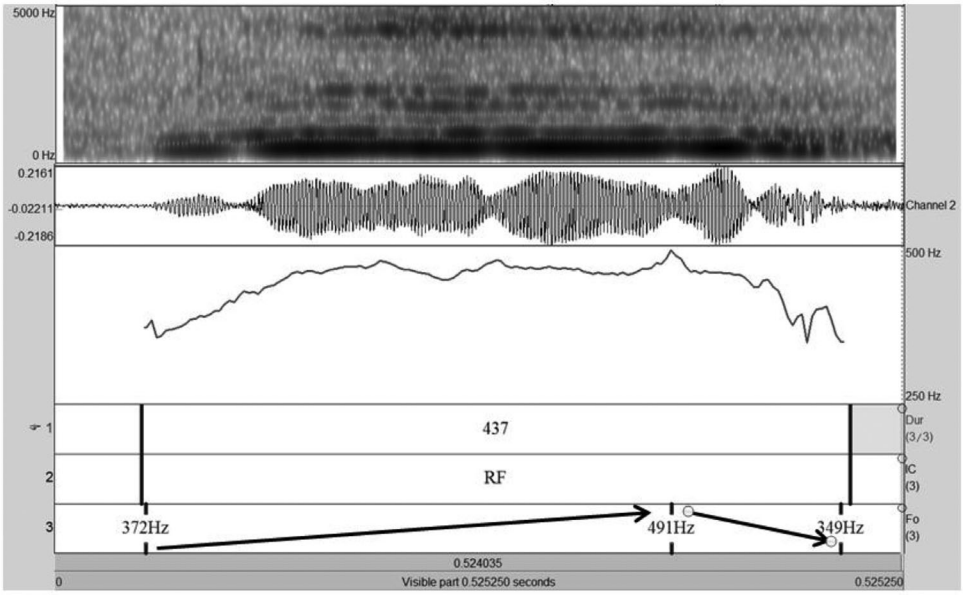

FIGURE 1. Infant vocalization analysis (duration = 437 ms, contour = rising from 372 Hz to 491 Hz, then falling from 491 Hz to 349 Hz).

Steffens, 2000). A total of 126 audio sequences were excluded. Altogether, 714 (LDA: $n = 209$; TD: $n = 505$) infants' utterances were rated.

Data from pitch contour were recoded into a nominal scale. Interrater reliability is good to excellent, pitch contour: $K = .92$, intraclass corealtion coefficient (ICC) = .94; pitch: $r = .73$, $p < .001$, $\alpha = .82$, ICC = .69; Duration: $r = .99$, $p < .001$, $\alpha = .99$, ICC = .99.

Duration and pitch. Results are shown in Table 3. For the duration comparison, a t test on independent samples was performed because the data did not deviate from normality. For mean fundamental frequency, the data were nonnormal, and a nonparametric test was performed (Mann–Whitney). There was no significant group difference in infants' utterance duration, $t(24) = -0.01$, $p = .994$, or in pitch, $z = -0.39$, $p = .701$.

Pitch contour. A contour profile was created for each infant, mentioning the percentage of every type of contour. We calculated the number of each type of contour among the total number of contours. Fl, R, and F contours were grouped into simple contour type. RF and FR were grouped into a one-inflection contour, and other contours were grouped into two- (or more) inflections contours. Results are shown in Figure 2.

We carried out a 6 (types of contours) × 2 (diagnosis) repeated measures analysis of variance. There was a linear interaction between types of contours and diagnosis, $F(1, 24) = 4.76$, $p = .039$. Simple effect analysis (effect of diagnosis on each type of contour) showed that there is no difference between groups

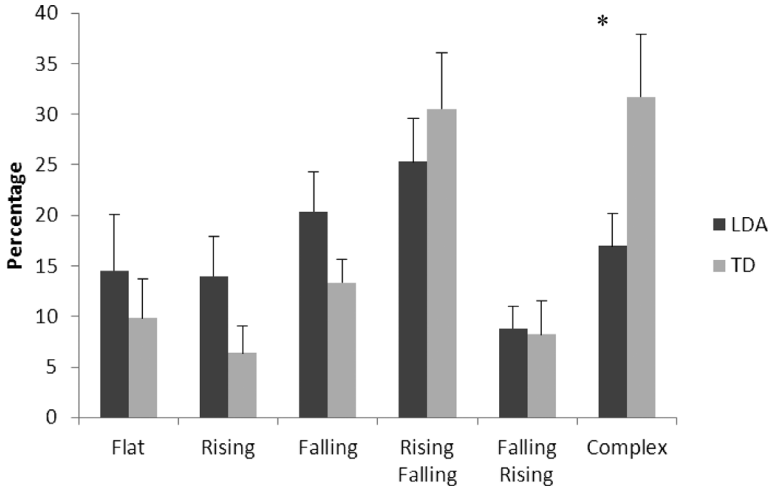

FIGURE 2. Histogram of infants' contour profiles by group.

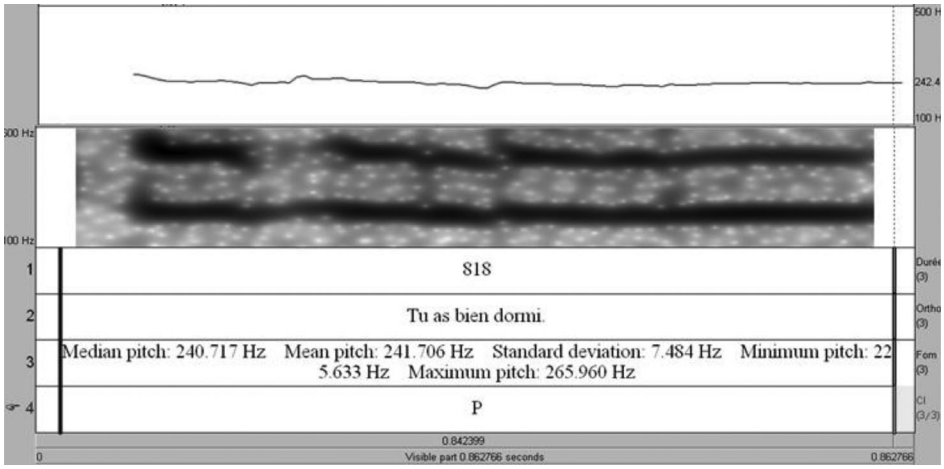

FIGURE 3. Mother talking to a 2-month-old infant (flat contour) ("Tu as bien dormi." means "You have slept well.").

for the first five types of contours (Fl., F, R, FR, RF), Fs(1, 24) < 7.59, ps > .124, but LDA infants displayed significantly fewer complex contours than did TD infants, $F(1, 24) = 14.76$, $p = .045$. When merging together all the simple contours (Fl, R, F), results showed that LDA infants use significantly more simple contours ($M = 48.93$, $SD = 19.055$) than did TD infants ($M = 29.55$, $SD = 17.251$), $t(24) = 2.72$, $p = .012$.

STUDY 2: MOTHERS' UTTERANCES

Method

Participants. Mothers appearing in family home movies and talking to their infant were included in the second study. Fathers were excluded from this study because there were too few of them in the videos. Mothers with fewer than three utterances ($n = 9$) also were excluded.

The sample for Study 2 included 12 mothers with an LDA infant and 11 mothers with a TD infant. We do not have accurate information about mothers' age or socioeducational level, but mothers who take part in this kind of study generally have a high level of education. Every utterance was extracted and analyzed (Figure 3) by two raters (first two authors) who were blind to diagnosis. Mothers' productions are all in French; the raters were native French speakers.

Results

Interrater reliability. The two raters coded all the utterances. Interrater reliability was excellent, pitch contour: $K = .95$, ICC = .94; pitch: $r = .78$, $p < .001$, $\alpha = .87$, ICC = .78; Duration: $r = .97$, $p < .001$, $\alpha = .98$, ICC = .97.

Maternal utterances duration and pitch. Table 4 summarizes mothers' utterance data. A t test for independent samples was performed since the data were normally distributed. Mothers of LDA infants displayed shorter utterances than did mothers of TD infants, $t(21) = -2.13$, $p = .045$. There was no mean pitch difference, $t(21) = 0.53$, $p = .603$.

TABLE 3. *Infants's Mean Pitch and Duration*

M (*SD*)	LDA	TD	*t*(24)/Z Score	*p*
F_0 (Hz)	393.61 (107.19)	357.64 (37.17)	−0.39	.701
Duration (ms)	651.38 (185.25)	652.09 (262.07)	−0.01	.994

LDA = infants later diagnosed with autism; TD = typically developing infants; F_0 = fundamental frequency.

Intonation contours. Figure 4 shows the contour data from mothers. There was no interaction between contours and diagnosis, $F(1, 21) = 1.62$, $p = .217$. All in all, mothers talking to LDA infants and mothers talking to TD infants used the same amount of each type of intonative contour, $F(1, 21) = 0.93$, $p = .345$.

DISCUSSION

This study examined if mothers and infants produce similar prosodic productions whether the infants were LDA or TD. Our findings show that LDA infants tend to display very early an atypical way of expression. The difference between the two groups is not quantitative but rather qualitative. LDA infants' productions are of the same duration and pitch as those of the TD infants,

TABLE 4. *Mothers' Utterances' Pitch and Mean Duration (SD)*

M (*SD*)	LDA	TD	*t*(21)	*p*
F_0 (Hz)	320.81 (50.72)	311.07 (35.53)	0.53	.603
Duration (ms)	926.71 (247.27)	1188.59 (339.87)	−2.13	.045*

LDA = infants later diagnosed with autism; TD = typically developing infants; F_0 = fundamental frequency.

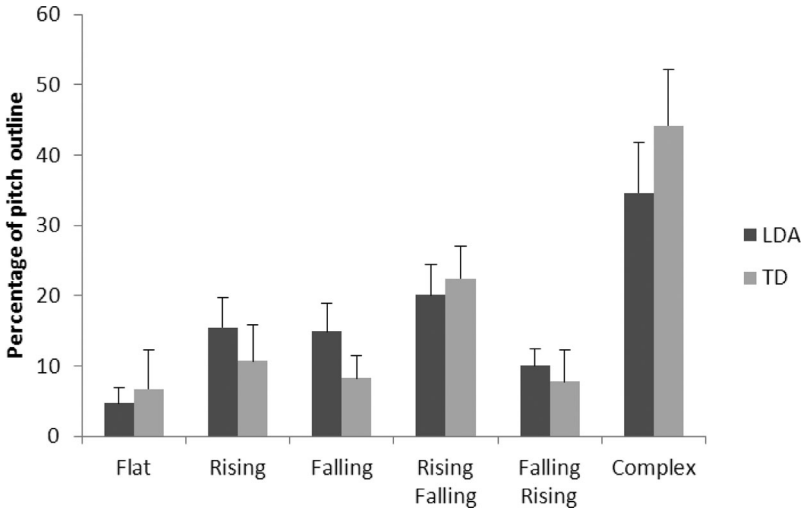

FIGURE 4. Mothers' pitch contour profile by group.

but their voice already is more monotonous since they use significantly fewer complex contours and more simple contours than do TD infants.

Our results thus provide additional evidence that autism affects precociously different spheres—social, cognitive, and linguistic—of child development. LDA infants produce the simplest intonation contours while TD infants produce relatively more complex intonation contours. In LDA infants, this might reflect difficulty in reproducing what they hear and/or in discriminating linguistic input. Usually, reinforcement and imitation play a significant role in learning language (Adamson, Deckner, & Bakeman, 2010). Research has shown that infants are responsive to language from birth (and before) (Bertoncini, Bijeljac-Babic, Blumstein, & Mehler, 1987; Christophe, Mehler, & Sebastian-Gallos, 2001; Jardri, Houfflin-Debarge, & Delion, 2012; Kisilevsky, Hains, & Brown, 2009; Nazzi, Bertoncini, & Mehler, 1998). Is it therefore a problem of input encoding or a problem of production ability? Our data do not provide an answer to this question, and even if they could, an outstanding question is whether this is a deficit or a delay. It would be useful to conduct an interactive analysis to identify which types of sounds LDA infants respond to the most, and whether they are different than the sounds to which TD infants respond. It also would be important to explore the developmental aspect of LDA infants' productions, which was not possible in this study due to the small number of participants and the variable availability of family videos (i.e., some families film more often and/or more regularly than do others).

Concerning the mothers' speech, analyzed utterances are shorter when talking to an LDA infant. Mothers having an LDA infant do not differ from other mothers on pitch or intonative contours. One possible explanation for these different lengths of utterances could be the lack of LDA infant responsiveness (Adrien, Faure et al., 1991; Adrien, Perrot, Hameury et al., 1991). Indeed, when the infant does not answer by looking at the mother, the latter tries to attract the infant's attention by calling him or her by name or nickname, using onomatopoeia, or playing peek-a-boo. These utterances are shorter in nature. Little by little, since they do not receive enough encouraging feedback, mothers could be less inclined to talk at length. It could be useful to follow mothers month by month during the first year of their infant's life to show the precise evolution of their vocal productions' characteristics.

Each language has its own prosodic structure (e.g., Cruttenden, 1997; Levitt, 1993). However, whatever the structure, it seems reasonable to expect similar differences in other languages to those we found in French samples. It would be worthwhile to replicate this study in different countries and linguistic groups.

Several studies have been carried out on sequences of early interaction with parents (Adrien, Faure et al., 1991; Adrien et al., 1993; Adrien, Perrot, Hameury et al., 1991; Adrien, Perrot, Sauvage et al., 1991; Maestro et al., 2005; Maestro et al., 2002; Osterling & Dawson, 1994; Osterling et al., 2002; Wetherby et al., 2007; White et al., 2007), but none on the analysis of vocal productions. Our data also are consistent with the findings of Mahdhaoui et al. (2011), who developed a computerized algorithm to detect IDS. Their ultimate objective is to successfully validate this program using home movies of children with autism. They assumed that IDS should be correlated with positive interactions both in autistic and nonautistic children (but to a lesser extent in autistic children) and that in early onset autism, IDS would decrease over time in terms of relative frequency due to a lack of interactive feedback from the child (Muratori & Maestro, 2007).

Some limitations must be taken into account for further studies. Sample size should be increased and should include a group with mental disabilities. With equivalent-sized groups, we also could have matched the participants on gender and developmental level for infants, and on socioeconomic level and pitch-based tessitura for mothers. With more participants, we could have run a longitudinal analysis to see the month-by-month evolution. Our extracted utterances were of good quality, but the ideal conditions would be to follow a sample from a prospective study (e.g., infant siblings of autistic children, who are at higher risk of autism). In such conditions, we could control the method of recording the

utterances. In our study, we were very careful when selecting the best quality utterances. Planned recordings would improve the quality of data, relative to retrospective research. This preliminary study, however, shows that autism could be linked to very early prosodic dysfunctions, so it is very important to carry out longitudinal studies at this point.

CONCLUSION

Analyzing family home movies helped us to more clearly chart the early development of LDA infants. Few studies have analyzed speech for early signs of autism from vocal productions. We have shown particular vocalizations in infants who were later diagnosed with autism (monotonous contours) as well as those in mothers' speech directed toward these infants (shorter utterances). Our results should be replicated to better understand the development of vocal productions of LDA infants through interactive situations with their parents.

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