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Atypical Prosody in Asperger Syndrome: Perceptual and Acoustic Measurements

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Abstract It is known that individuals with Asperger syndrome (AS) may show no problems with regard to what is said (e.g., lexical content) but tend to have difficulties in how utterances are produced, i.e., they may show prosodic impairments. In the present study, we focus on the use of prosodic features to express grammatical meaning. Specifically, we explored the sentence type difference between statements and questions that is conveyed by intonation, using perceptual and acoustic measurements. Children aged 8 and 9 years with AS ($n = 12$) were matched according to age and nonverbal intelligence with typically developing peers ($n = 17$). Although children with AS could produce categorically accurate prosodic patterns, their prosodic contours were perceived as odd by adult listeners, and acoustic measurements showed alterations in duration and pitch. Additionally, children with AS had greater variability in fundamental frequency contours compared to typically developing peers.

Keywords Asperger syndrome · Atypical prosody · Autism spectrum disorders · Intonation

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Introduction

Prosody can be defined as the "level of linguistic representation at which the acoustic–phonetic properties of an utterance vary independently of its lexical items" (Wagner and Watson 2010, p. 905). It comprises a variety of phenomena, such as intonation (the melody of speech), phrasing (chunking the speech continuum), prominence (highlighting words or phrases), and rhythm (the cadence of speech), and it may convey several dimensions of meaning. The meanings expressed by prosody can be affective meanings that are related to the state of the speaker (e.g., friendliness, confidence, surprise), or informational meanings that are related to the linguistic message (e.g., questioning, asserting, emphasis; Gussenhoven 2004; Järvinen-Pasley et al. 2008; Peppé 1998). Some informational meanings have been conventionalized and encoded in the grammar of many languages. This is the case of raised pitch to signal questions, and of low pitch that tends to characterize statements (Gussenhoven 2004). In the present study we focus on the use of prosodic features to express grammatical meaning; specifically, we explore the sentence type distinction between statements and questions in the speech of children with Asperger syndrome (AS) and typically developing peers, using perceptual and acoustic measurements.

Prosody has been intensively studied in typically developing children because prosody processing is an integral part of language acquisition, in perception and in production (e.g., Cutler and Swinney 1987; Morgan and Demuth 1996). Decades of research, especially within the prosodic bootstrapping model, have shown that the development of prosodic sensitivity emerges in the early years before phonology, syntax, and semantics (e.g., Christophe et al. 2001; Crystal 1979; Mehler et al. 1988; Morgan and

Demuth 1996). Prosodic cues are involved in the development not only of word segmentation skills, but also of grammatical categories and basic syntactic structures (e.g., Christophe et al. 1997; Höhle 2009). Overall, prosody appears to play a pivotal role in language acquisition, at least in typically developing children. Prosody has also been studied in children with developmental disorders, namely speech and language disorders (e.g., Wells and Peppé 2003), Williams syndrome (e.g., Catterall et al. 2006), deafness (e.g., Parker and Rose 1990), and—critical to the present work—autism spectrum disorders (ASD) (e.g., Baltaxe and Simmons 1985).

About 20–30 in 10,000 individuals worldwide have a diagnosis within the ASD (Fombonne 2009), which includes autism, pervasive developmental disorder not otherwise specified (PDD-NOS), Rett's disorder, child disintegrative disorder, and AS. ASD is a neurodevelopmental condition characterized by a complex group of manifestations involving some degree of difficulty in communication and interpersonal relationships, as well as obsessions and repetitive behaviors (American Psychiatric Association 2000). Prosodic impairments are one of the earliest signs of ASD (e.g., Tager-Flusberg et al. 2005). These impairments range from subtle deviations with no impact on comprehension to severe distortions that undermine communication (Bonneh et al. 2011; DePape et al. 2012; Diehl et al. 2009; Green and Tobin 2009. In either case, they may become a barrier to social interaction and approval (Shriberg et al. 2001). Importantly, prosodic atypicalities often persist even when other areas of language improve (McCann and Peppé 2003), and they may continue throughout life (e.g., Baltaxe and Simmons 1985; Paul et al. 2009; Schoen et al. 2010; Tager-Flusberg et al. 2005).

Prosodic impairments in ASD have been examined from the viewpoint of production, and from the viewpoint of perception. Expressive difficulties have been uncovered in rhythm, rate of speech, and intonation patterns (e.g., McCann and Peppé 2003; Paul et al. 2005; Shriberg et al. 2001), and in the use of prosody to convey phrase-level stress (McCann et al. 2007). However, several findings are contradictory. Monotone intonation has been reported, but so has exaggerated intonation (Baltaxe and Simmons 1985; Bonneh et al. 2011; DePape et al. 2012; Kanner 1943; Sharda et al. 2010); slow syllabic speech, but also fast articulatory rate, have been reported too (Baron-Cohen and Staunton 1994; for a review, see McCann and Peppé 2003). Recently, Nadig and Shaw (2012) observed increased pitch range during conversation and structured communication in children with high-functioning autism. This led them to suggest that, contrary to the widespread stereotype of flat intonation, exaggerated intonation is a prosodic landmark of autism in children. Furthermore, it is also true that many individuals with ASD (especially children with AS) score very well on prosodic tasks such as the production of grammatical stress (Paul et al. 2005; Peppé et al. 2011). Yet no convincing explanation has been provided in the literature for these discrepant findings. From the viewpoint of perception/comprehension, children with ASD were shown recall stressed words better than unstressed ones (Fine et al. 1991), to discriminate word pairs differing in first- versus last-syllable stress patterns (Grossman et al. 2010), and to distinguish sentence types such as statements versus questions (Paul et al. 2005; Peppé et al. 2007, 2011). However, receptive impairments have also been found in ASD. Paul et al. (2005) reported significant deficits in the perception of emphatic stress, and according to Peppé et al. (2007) there are delays or impairments in the acquisition of receptive prosody, such as the tendency to perceive pairs of the same auditory stimuli as prosodically different. Impairments in receptive prosody may have an impact on production, and so in order to better understand how individuals with ASD process prosody and what their sociocommunicative difficulties are, a combined viewpoint of production and perception might be advantageous. The evaluation of expressive and receptive prosodic skills using acoustic analyses as well as perceptual measures could also improve the quality of assessment and differential diagnosis, and have positive implications for intervention in individuals with ASD.

As no consensus has emerged on the characterization of the prosodic profile in ASD, in this study we focus on one subtype only: AS. Individuals with AS do not have a history of language delay, and their cognitive development is within the normal range; nevertheless, they show significant impairments in social interaction, imagination, and communication, particularly involving pragmatics and prosody (as in ASD; American Psychiatric Association 2000; Klin et al. 2000). We also focus on one type of linguistic prosody: the distinction between statements and questions through the modulation of intonation. Statements and questions are frequent sentence types, which are crucial for communication. Intonation is one of the most frequent means to distinguish a question from a statement in most languages of the world (Dryer 2011). For example, in European Portuguese this sentence type contrast is conveyed by pitch contour (Frota 2002; Falé and Faria 2005; Frota et al. 2013). As prior studies have revealed prosodic difficulties, but not impairment in understanding and producing statements and questions in individuals with autism (Koegel et al. 2010; Paul et al. 2005; Peppé et al. 2007), we aimed to examine this specific contrast in the prosody of AS children. To this end, we used the Turn-End subtest of the Profiling Elements of Prosody in Speech-Communication (PEPS-C; Peppé and McCann 2003). Our participants were Portuguese children (speakers of European Portuguese) with AS and typically developing peers, and we examined whether the use of intonation to differentiate questions from statements was impaired in AS children. First, we analyzed whether the children could categorically comprehend and produce statements or questions. Secondly, we studied the acoustic parameters of the children's productions in order to identify whether the speech of AS children differed in duration, pitch, and intensity from that of their peers. Additionally, in order to obtain a perceptual characterization of prosodic atypicality, we examined if the utterances produced by the children were perceived as sounding natural or odd by adult listeners who were unaware of whether they came from AS or typically developing children.

Method

Participants

Twenty-nine Portuguese children participated in this study, 12 with AS and 17 typically developing (TD) peers. The clinical group included 10 boys and 2 girls aged between 8 and 9 years ($M = 8.58$, $SD = 0.51$); they all met the ICD-10 (World Health Organization 1992) and DSM-IV-TR (American Psychiatric Association 2000) criteria for AS. The Autism Diagnostic Interview-Revised (ADI-R; Lord et al. 1994) and the Autism Diagnostic Observation Schedule (ADOS; Lord et al. 1989), both adapted to the Portuguese language, were used to establish the diagnosis. In agreement with the DSM-IV-TR, no children with signs of schizophrenia, obsessive–compulsive disorder, attention deficit hyperactivity disorder, or learning disorders were included in the AS group. These children attended special classes for ASD children set in mainstream public schools, as is typical in Portugal (an inclusive public education system). The children from the TD group were 10 boys and 7 girls matched to the AS children on age ($M = 8.35$, $SD = 0.49$) and nonverbal intellectual level, as assessed with the Raven's Coloured Progressive Matrices (Raven's CPM; Raven 1995) (see Table 1). They were attending the first and second years of elementary school; none had learning difficulties, according to teacher and/or parent reports. All children scored within the normal range in the Raven's CPM test (Portuguese adaptation and norms by Simões 2000).

Table 1 Mean (M), standard deviation (SD), and range for age and score in Raven's coloured progressive matrices (RCPM) in the Asperger syndrome (AS) and typically developing (TD) children

Group	*M*	*SD*	Range
AS ($N = 12$)			
Age	8.58	0.51	8–9
RCPM score	23.42	3.72	17–29
TD ($N = 17$)			
Age	8.35	0.49	8–9
RCPM score	27	4.84	18–32

An additional group of 35 undergraduate students participated in the study. They were on average 22.11 years old ($SD = 4.88$) and attended a Master's in Education program at the University of Aveiro. Their task was to rate how natural the children's one-word productions sounded. All participants (children and undergraduate students) were native speakers of European Portuguese. The children were born and raised in monolingual homes in the region of Porto. None of the participants had hearing difficulties or uncorrected visual problems. Informed consent was obtained from the children's parents or caregivers and from the adult participants.

Material

The Turn-End subtest of the PEPS-C (Peppé and McCann 2003) adapted to European Portuguese (Filipe and Vicente 2011) was used to capture the children's ability to distinguish statements from questions. The PEPS-C test assesses receptive and expressive prosodic skills of children aged 4 and above, and it is composed of two types of tests, called formal and functional level tests. Formal level tests assess auditory discrimination and voice skills, and functional level tests assess the communicative categories of affect, chunking, focus, and turn-end, which we use here. The Turn-End subtest has two tasks—receptive and expressive—each with 20 items (2 examples + 2 training items + 16 experimental items). In the receptive task, participants are given two pictures, one representing statements (a child reading a book depicting a food item) and the other representing questions (the child offering a food item), and then hear a word produced with either falling or rising intonation (e.g., *Carrot. or Carrot?*). Their task is to indicate whether they heard a statement or a question by pointing to the corresponding picture. In the expressive task, the child is presented with the same pictures, one by one, and the task is to produce in the corresponding intonation the name of the food item being shown (e.g., if the child is reading, the name of the food item shown should be stated; if the child is offering, it should be produced as a question). A digital recorder was used to record all the children's productions.

For the atypicality judgments done by the adult participants, the one-word utterances produced by each child were digitally prepared. The 16 utterances corresponding to the experimental trials were arranged sequentially with a 4-s inter-stimulus interval; 29 tapes were produced, one per child.

Procedure

The children were assessed in a quiet room of their school, in one individual session lasting for approximately 30 min. They completed the Turn-End subtest starting with the receptive task followed by the productive one, as described in the "Materials" section. The session was recorded for subsequent analyses of the children's utterances. The distance of the speaker from the recorder was kept constant at approximately one foot.

The adult participants listened to the 29 tapes of the children's productions in the expressive task. The tapes were presented in a pseudorandom order with an interval of 10 s between tapes. The adults were asked to judge the typicality of the utterances disregarding articulation errors or regional accents. A 5-point scale from 1, *common,* to 5, *uncommon,* was used to rate how natural or odd they sounded. Judges had no information about the objectives of the study, nor that the utterances came from two groups of speakers.

For the acoustic analyses, the one-word utterances produced by the children in the expressive task were spliced into individual sound files (one per word), and the duration, pitch (range, mean, maximum, and minimum), and intensity (mean, maximum, and minimum) were measured. PRAAT software (Boersma and Weenink 2011) was used for all the acoustic measurements.

All the statistical analyses were calculated with IBM® SPSS version 20.0.

Results

Results for the Turn-End subtest are shown in Fig. 1. An analysis of variance (one-way ANOVA) on the results obtained in the receptive task, with Group as a factor (AS vs. TD children), revealed that the performance of the two groups did not differ ($F < 1$; AS: $M = 14.50$, $SD = 2.61$; TD: $M = 13.67$, $SD = 2.77$). In the expressive task, the average scores were similar in the two groups (AS: $M = 12.62$, $SD = 3.39$; TD: $M = 11.76$, $SD = 3.81$; F (1, 27) = 1.521; *ns*).

Regarding perceptual analyses, blind judges perceived AS children's productions as sounding significantly more atypical or uncommon than those from TD children [$M = 3.42$ vs. 2.39, respectively, for AS and TD; F (1, 27) = 10.98; $p = 0.003$; $\eta^2 = 0.202$]. Figure 2 shows box plots for the typicality ratings of the two groups.

The acoustic measurements are given in Tables 2 and 3 for statements and questions, respectively. Box plots for the acoustic measurements separately by group are shown in Fig. 3.

As the prosodic aspects of speech are acoustically reflected in fundamental frequency, duration, and intensity, a multivariate analysis of variance (MANOVA) was carried out to assess whether the factor Group (TD vs. AS children) had a significant effect on these variables. The MANOVA revealed a significant effect of Group, F (1, 27) = 5.216; $p = 0.03$; $\eta p^2 = 0.612$; power = 0.941. In order to further specify whether the pattern of acoustic measurements for statements and questions differed between groups, analyses of variance with Modality (statements vs. questions) as within-subject factor and

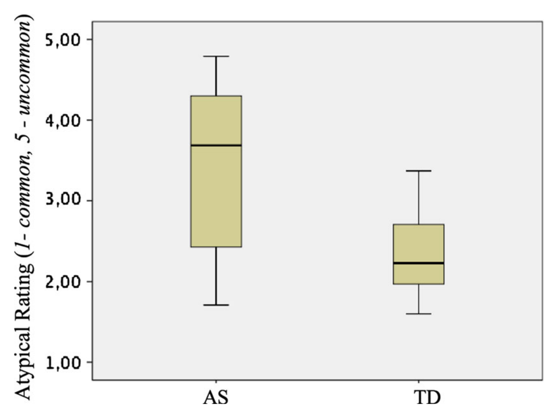

Fig. 2 Box plots for the atypicality ratings given to utterances from Asperger Syndrome (AS) and typically developing (TD) children

Fig. 1 Box plots for the receptive (*left*) and expressive (*right*) Turn-End subtest in the Asperger Syndrome (AS) and typically developing (TD) children

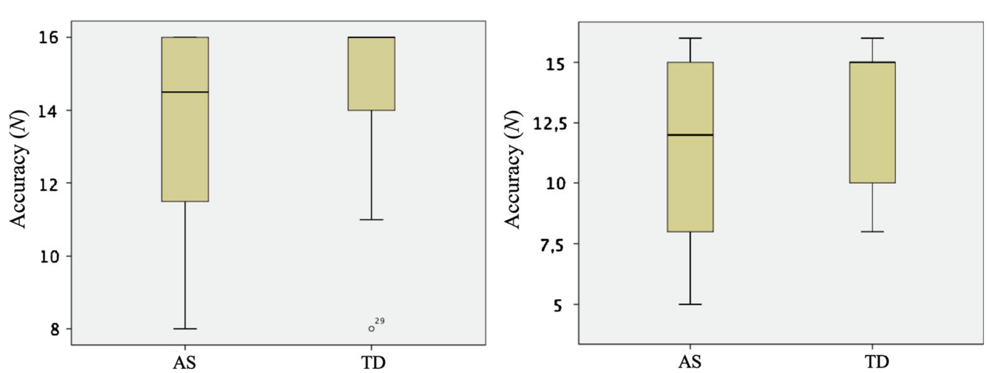

Table 2 Statements: mean (M), standard deviation (SD), and range of acoustic parameters in Asperger syndrome (AS) and typically developing (TD) Children

Parameters	*M*	*SD*	Range
Duration*			
AS	1.08	0.17	0.86–1.40
TD	0.89	0.12	0.70–1.12
Pitch range*			
AS	108.63	40.58	50.59–179.74
TD	70.67	27.14	19.67–126.37
Mean pitch*			
AS	243.30	24.23	204.75–285.32
TD	224.33	25.81	188.06–271.24
Maximum pitch*			
AS	255.11	36.81	199.59–343.59
TD	222.04	28.33	181.57–276.39
Minimum pitch			
AS	146.55	23.78	102.45–176.54
TD	151.11	21.86	108.39–186.85
Mean intensity			
AS	72.87	3.07	68.82–77.89
TD	70.52	4.86	61.89–76.05
Maximum intensity			
AS	79.29	2.76	75.52–83.80
TD	76.21	4.93	66.71–82.63
Minimum intensity			
AS	47.93	2.81	43.36–54.29
TD	47.76	6.29	26.13–53.45

* $p < 0.05$

Table 3 Questions: mean (M), standard deviation (SD), and range of acoustic parameters in Asperger syndrome (AS) and typically developing (TD) Children

Parameters	*M*	*SD*	Range
Duration*			
AS	1.08	0.13	0.84–1.34
TD	0.88	0.88	0.70–0.99
Pitch range*			
AS	175.97	54.22	88.80–249.91
TD	124.32	45.61	56.51–209.00
Mean pitch*			
AS	286.14	22.15	249.32–322.77
TD	261.14	31.36	211.02–327.00
Maximum pitch*			
AS	332.26	41.81	256.19–395.22
TD	281.71	48.61	204.26–378.79
Minimum pitch			
AS	156.29	24.50	118.45–183.71
TD	157.98	20.55	111.75–178.72
Mean intensity			
AS	77.13	2.69	71.87–81.08
TD	75.12	3.80	67.67–80.76
Maximum intensity			
AS	83.00	2.82	79.50–87.05
TD	81.03	3.69	75.07–87.25
Minimum intensity			
AS	49.09	3.22	44.28–57.59
TD	50.84	5.28	35.66–57.46

* $p < 0.05$

Group (AS vs. TD) as between-subject factor were conducted for each acoustic parameter. The average duration of statements ranged from 0.86 to 1.40 s in the AS group, and from 0.70 to 1.12 s in the TD group ($M = 1.08$ vs. 0.89, $SD = 0.17$ vs. 0.12, respectively). The average duration of questions ranged between 0.84–1.34 s in the AS group and between 0.70–0.99 s in the TD group ($M = 1.08$ vs. 0.88, $SD = 0.13$ vs. 0.88, respectively). The analysis of variance revealed that duration was longer in the AS group, for statements as well as for questions [for Group, $F\ (1,\ 27) = 19.72$; $p < 0.001$; $\eta^2 = 0.422$; no interaction]. Pitch range was also higher in AS children than in their TD peers, for statements ($M = 108$ vs. 70, $SD = 40$ vs. 27, respectively) and for questions [$M = 175$ vs. 124, $SD = 54$ vs. 45, respectively; $F\ (1, 27) = 13.06$; $p = 0.001$; $\eta^2 = 0.326$]. Mean pitch was also significantly increased in the AS group, both for statements ($M = 243$ vs. 224) and questions [$M = 286$ vs. 261; $F\,(1, 27) = 6.32$; $p = 0.018$; $\eta^2 = 0.190$]. The same pattern was observed for maximum pitch, higher in AS children than in their peers, for statements ($M = 255$ vs. 222, $SD = 36$ vs. 28, respectively) and questions [$M = 332$ vs. 281, $SD = 41$ vs. 48, respectively; $F\ (1,\ 27) = 14.71$; $p = 0.001$; $\eta^2 = 0.353$].

By contrast, no differences between AS and TD children were found for minimum pitch (statements: $M = 146$ vs. 151, $SD = 23$ vs. 21; questions: $M = 156$ vs. 157, $SD = 24$ vs. 20; $F < 1$). Also, no differences were found in the intensity parameters [mean intensity for statements $F\,(1, 27) = 2.453$, *ns,* for questions, $F\,(1, 27) = 2.175$, *ns;* minimum intensity for statements $F < 1$, for questions $F\ (1, 27) = 1.034$, *ns*; maximum intensity for statements $F\ (1, 27) = 3.792$, *ns,* for questions: $F\ (1, 27) = 2.928$, *ns*]. Additionally, in order to see if the results could be biased due to the small number of girls in the clinical group, the results were analyzed again without the girls and the pattern of results remained the same.

A standard multiple regression was used to assess the success of different models including significant parameters as predictors of atypicality judgments. All predictor variables were included in the backward stepwise method (see Table 4). The best-fit model [$R^2 = 0.63$, F (5,

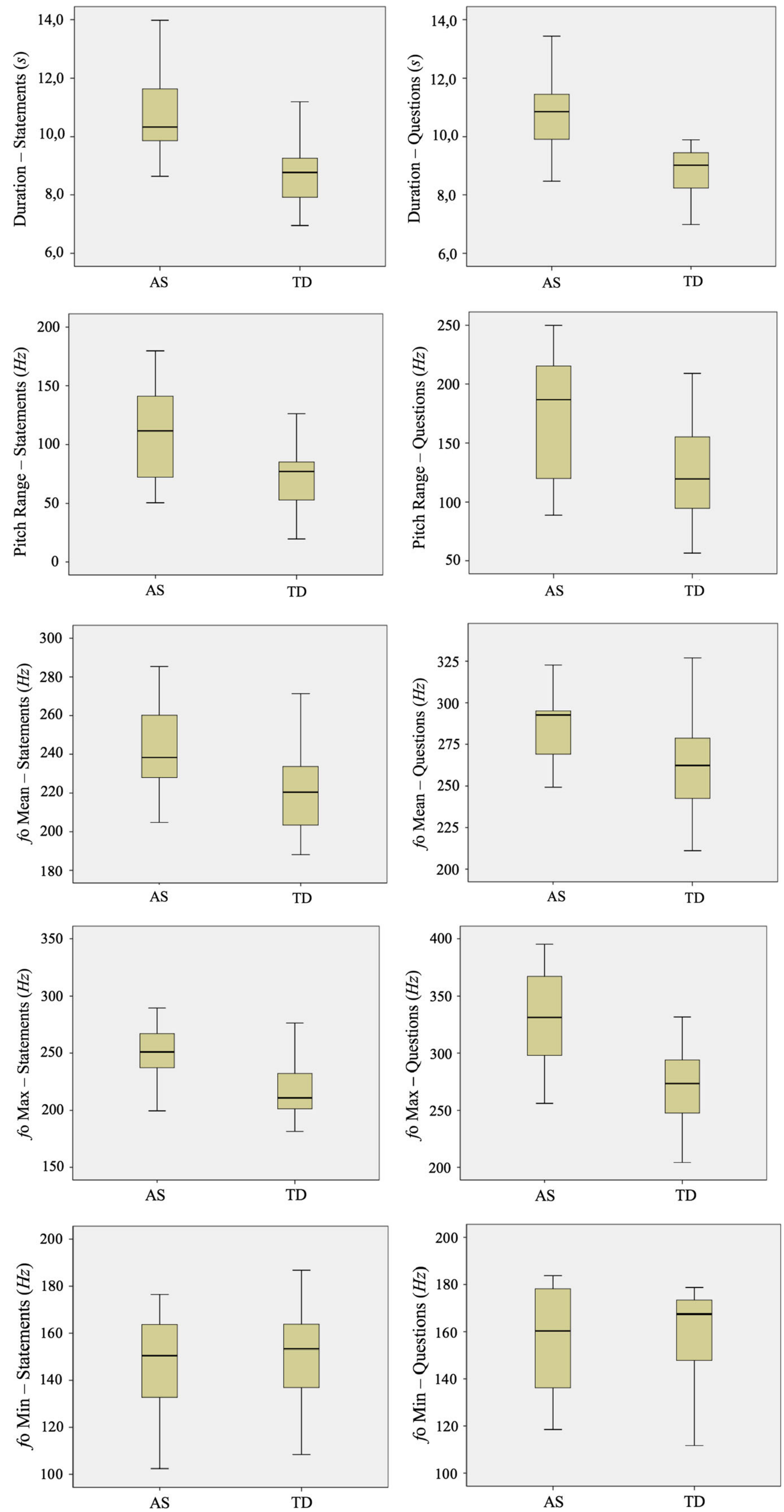

Fig. 3 Box plots for acoustic measurements (duration, pitch range, *f*0 mean, *f*0 max, and *f*0 min) of utterances from Asperger syndrome (AS) and typically developing (TD) children

Table 4 Regressions predicting atypical prosody

	β	SE	p value
Model 1			
Maximum pitch interrogative	0.712	0.001	0.296
Maximum pitch declarative	−0.443	0.001	0.290
Mean pitch interrogative	−0.644	0.010	0.066
Mean pitch declarative	0.399	0.012	0.249
Span pitch interrogative	−0.176	0.001	0.752
Span pitch declarative	−0.106	0.001	0.758
Duration declarative	0.079	0.000	0.816
Duration interrogative	0.709	0.000	0.047
Adjusted R^2	0.58		
Model 2			
Maximum pitch interrogative	0.733	0.001	0.267
Maximum pitch declarative	−0.475	0.001	0.220
Mean pitch interrogative	−0.665	0.010	0.045
Mean pitch declarative	0.440	0.010	0.134
Span pitch interrogative	−0.200	0.001	0.708
Span pitch declarative	−0.081	0.001	0.799
Duration interrogative	0.775	0.000	<0.001
Adjusted R^2	0.60		
Model 3			
Maximum pitch interrogative	0.803	0.001	0.174
Maximum pitch declarative	−0.557	0.001	0.008
Mean pitch interrogative	−0.684	0.009	0.031
Mean pitch declarative	0.475	0.009	0.063
Span pitch interrogative	−0.266	0.001	0.560
Duration interrogative	0.766	0.000	<0.001
Adjusted R^2	0.62		
Model 4			
Maximum pitch interrogative	0.499	0.000	0.050
Maximum pitch declarative	−0.586	0.000	0.004
Mean pitch interrogative	−0.605	0.008	0.030
Mean pitch declarative	0.525	0.008	0.028
Duration interrogative	0.749	0.000	<0.001
Adjusted R^2	0.63		

23) = 10.484; $p = < 0.001$] for predicting atypical prosody was composed by question maximum pitch (β = 0.499), statement maximum pitch (β = −0.586), question mean pitch (β = −0.605), statement mean pitch (β = 0.525), and question duration (β = 0.749).

An inspection of the fundamental frequency contours revealed that the productions of AS speakers were characterized by heterogeneous contour patterns, unlike the productions of their TD peers that were overall more consistent. This is in line with the higher variability (*SD* values for pitch range and maximum pitch) found in the utterances produced by AS children compared to the TD children.

Discussion

The aim of the present study was to examine how children with AS use prosody to distinguish statements from questions and to identify potential markers of prosodic impairment in this clinical population. Because previous findings on prosodic abilities in AS have several inconsistencies, the focus here was set on the combination of perception and production approaches, and on the acoustic characterization of the children's one-word productions. The results showed that prosodic contours associated with statements and questions in children with AS were categorically accurate in perception (receptive skills) and in production (expressive skills): children with AS performed similarly to TD children in the comprehension of the two intonation patterns and in the production of the two prosodically different categories. However, acoustic measurements of the utterances from AS children showed alterations in duration and pitch, and children with AS had greater variability in fundamental frequency contours compared to TD peers. Additionally, adults unaware of the origin of the utterances rated those produced by AS children as atypical in comparison with the one produced by TD peers. These findings indicate that although children with AS have no impairment in discriminating the prosody of statements and questions, in perception as well as in production, more subtle aspects of the acoustic form of the utterances are affected.

Our results did not find any differences between children with AS and TD peers in the production and perceptual classification of statements and questions. These results are consistent with those obtained by Paul et al. (2005) and Peppé et al. (2007, 2011) for English. Therefore, this particular prosodic ability seems to be accurate in children with AS. Also in line with previous findings for lexical stress production, emotional sentence production, or speech-like vocalizations (e.g., Schoen et al. 2010; Grossman et al. 2010; Peppé 2007; Grossman et al. 2013), judges identified atypicality in productions of children with AS. Interestingly, previous studies of prosody in high-functioning autism using perceptual ratings have also found atypical prosody in these individuals (Nadig and Shaw 2012; Shriberg et al. 2001). Therefore, atypical prosody can be considered a hallmark of the autistic spectrum. These atypicalities in expressive prosody may induce the listener to perceive the utterances as odd, and this can have implications for social interaction. Atypical perception of prosody has severe consequences for social integration, as documented in literature (e.g., Baron-Cohen and Staunton 1994; Paul et al. 2005).

Studies of prosody in autism have disclosed specific acoustic patterns in the speech of children with AS. Monotonous speech and narrow F0 range has traditionally been described as characteristic of autism (Kanner 1943).

However, in line with our results, greater variability in pitch and higher pitch peaks have been documented in several studies, in spite of no differences in minimum pitch and intensity parameters (Bonneh et al. 2011; DePape et al. 2012; Diehl et al. 2009; Diehl and Paul 2013; Green and Tobin 2009; Sharda et al. 2010; Shriberg et al. 2001). Recently, Diehl and Paul (2013) also found characteristic acoustic patterns in the speech of children with AS: they spoke more slowly than their peers. These findings are in line with the predictions of Bellon-Harn et al.'s (2007) hypothesis of a significant deficit in duration. The researchers found consistent deviation in rates and inappropriate pausing in the productions of children with AS. More recently, Demouy et al. (2011) suggested that prosodic features such as rising intonation can be markers of ASD pathology. The results of our study indicate that increased pitch variability may be a marker for AS, and that alterations in duration, mean and maximum pitch are good acoustic predictors of perceived atypicality of AS speech. Interestingly, these acoustic predictors seem to be independent of the children's native language, given the convergent results found in English and Portuguese AS children. Our results are also suggestive of specificities in fundamental frequency contours in AS. These contours have more consistent patterns in TD children, in contrast with the high variability of the F0 contours found in AS children. Taken as a whole, our findings show that increased pitch range is a consistent prosodic characteristic in the speech of AS children. Therefore, contrary to the common impression of monotonic speech in autism (Baltaxe and Simmons 1985), children with AS have greater variability in pitch than their TD peers. The same result was found in children with high and lower functioning autism (Baltaxe 1984; Diehl et al. 2009).

Although prosodic impairments in the autistic spectrum and their implications for the social context have been discussed in previous research (e.g., Baron-Cohen and Staunton 1994), no systematic study on prosody rehabilitation has, to our knowledge, been conducted. Therefore, research on prosody intervention is needed, and the results of the present study have several clinical and scientific implications in that field. From a clinical point of view, prosodic intervention should focus both on the categorical linguistic level (i.e., the comprehension and production of different grammatical meanings expressed by prosody), and on the acoustic level (i.e., the acoustic form of the prosodic patterns produced), targeting specific communicative goals and acoustic performance. Our results demonstrate that although children with AS do not have difficulties in perceiving and expressing at least one intonational distinction (between statements and questions), they can have impairments in the use of prosodic cues, namely duration and pitch related parameters.

From a more general point of view, the present study contributes to the knowledge on communication deficits in ASD. If specific prosodic impairments were found across ASD, this would provide insights into the nature and etiology of this disorder. Future studies should compare prosodic skills in different ASD groups to identify shared or specific acoustic profiles. As pointed out by Demouy et al. (2011), there is a clinical need to assess prosodic markers in the various pathological groups in order to refine ASD diagnostic criteria, and to specify language remediation strategies. Also, engineering technology to automatically assess prosodic ability has already proven able to distinguish between various pathologies (Oller et al. 2010; Warren et al. 2010), and better knowledge of prosodic profiles is crucial to improve the quality of these technologies.

In conclusion, this study provides evidence of acoustic specificities in the prosody of children with AS, with no apparent impact on the distinction between statements and questions conveyed intonational prosody. As expressive prosody plays a vital role in the way listeners react to a speaker, knowing more about the prosodic profile of these individuals would help to design better intervention strategies. However, further research is needed in order to address current limitations. First, studies should incorporate larger sample sizes to obtain representative findings. Second, other aspects of prosody (such as chunking or emphasis) need to be investigated to assess the generalizability of current findings. Third, it is necessary to explore prosodic measures in more naturalistic settings, such as conversations. Finally, the parameters analyzed may not capture all the factors that contribute to atypical expressive prosody (for example, a phonological analysis of intonation patterns in AS speech still needs to be done). In order to capture the extent of prosodic impairments in ASD, future work should address these issues.

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