Applied Psycholinguistics **30** (2009), 385–404
Printed in the United States of America
doi:10.1017/S0142716409090201

An acoustic analysis of prosody in high-functioning autism

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Received: October 31, 2007 Accepted for publication: November 14, 2008

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ABSTRACT
This paper examined the fundamental frequency variation in the narratives of individuals with high-functioning autism (HFA) and typical controls matched on age, IQ, and verbal abilities. Study 1 found increased fundamental frequency variation in the speech of 21 children and adolescents with HFA when compared to 21 typical controls. Study 2 replicated the findings from Study 1 with a younger sample of 17 children with HFA and 17 typical controls. In addition, Study 1 found evidence that acoustic measurements of prosody were related to clinical judgments of autism-specific communication impairments, although this was not replicated in Study 2. Taken together, these studies provide evidence for differences in expressive prosody in individuals with HFA that can be measured objectively.

Autism is a neurodevelopmental disorder that involves deficits in communication, impairments in social interaction, and the presence of repetitive or stereotyped patterns of behavior (American Psychiatric Association, 2000). In general, it is thought that there is enough variability in cognitive and linguistic abilities to consider autism a spectrum disorder (Rapin & Dunn, 2003; Rice, Warren, & Betz, 2005; Volkmar, Lord, Bailey, Schultz, & Klin, 2004). Individuals with normal intellectual abilities and/or normal language functioning are often defined as having high-functioning autism (HFA). Asperger syndrome and pervasive developmental disorder—not otherwise specified are sometimes included when discussing the high-functioning end of the autism spectrum. By definition, the diagnosis of Asperger syndrome does not have gross language delays in early development,

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https://doi.org/10.1017/S0142716409090201 Published online by Cambridge University Press

which differentiates it from autism (American Psychiatric Association, 2000), although the absence of gross language delays does not preclude pragmatic language deficits in these individuals (Shriberg et al., 2001).

Regardless of their specific diagnosis and functioning level, individuals with autism exhibit significant impairments in the pragmatic use of language (Tager-Flusberg, 2001; Young, Diehl, Morris, Hyman, & Bennetto, 2005). In particular, marked atypicalities in suprasegmental aspects of speech are considered a core feature of the disorder, and are one of the earliest atypical features to appear (Baltaxe & Simmons, 1992; Tager-Flusberg, 2001). Moreover, expressive prosody deficits persist even while other areas of language functioning improve (Shriberg et al., 2001), and prosodic differences have been found to be significantly related to ratings of social and communicative functioning in autism (Paul, Shriberg, et al., 2005). It is important that the understanding of prosody in typical and atypical development has lagged behind other areas of language, because until recently there has been a general lack of theoretical and methodological sophistication in investigating prosody production (Lord & Paul, 1997; Watson, Gunlogson, & Tanenhaus, 2006).

A wide variety of terminology has been used to describe prosodic patterns in this population. Even the earliest characterizations of the disorder described peculiar use of the tone of voice (Asperger, 1944, as translated by Frith, 1991; Kanner, 1946), but Asperger noted that "we do not intellectually understand many of these qualities and can only feel them intuitively" (Asperger, 1944, as translated by Frith, 1991, p. 70). Prosodic patterns in this population have been characterized with terms such as flat/monotonous, variable, sing-songy, and/or pedantic, among others (Amoroso, 1992; Baltaxe, 1984; Fay & Schuler, 1980; Goldfarb, Braunstein, & Lorge, 1956; Lord, Rutter, & Lecouteur, 1994; Provonost, Wakstein, & Wakstein, 1966). Prosody is commonly included as a diagnostic characteristic in clinical assessments of autism (Lord, Rutter, DiLavore, & Risi, 1999; Rutter, Le Couteur, & Lord, 2003). In these instruments, however, prosodic impairments are often broadly defined. Deviations in rate, rhythm, volume, intonation, or the inability to change language register based on the interlocutor (resulting in speech that sounds pedantic or inappropriate) all could represent the atypical prosody that is characteristic of autism. The wide-ranging characterization of prosodic deficits is the result of both the diversity of impairments within the population (Rapin & Dunn, 2003; Rice et al., 2005; Tager-Flusberg, 2004; Volkmar et al., 2004), and until very recently, the paucity of studies using objective measurements of prosodic deficits (McCann & Peppé, 2003; Watson et al., 2006).

RESEARCH ON PROSODY PRODUCTION IN AUTISM SPECTRUM DISORDERS

A variety of measurement techniques have been used to study expressive prosody in autism spectrum disorders. Unfortunately, the presence and proper delineation of related diagnoses such as Asperger syndrome is an area of considerable disagreement (Miller & Ozonoff, 2000; Volkmar et al., 2004). Therefore, for the purpose of this review, we will use the group labels as defined by the each of the

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studies, but we will consider the work as part of prosody functioning in the entire autism spectrum.

Standardized measures have shown some sensitivity to prosody production deficits in some (but not all) participants with autism. Shriberg et al. (2001) used the Prosody Voice Screening Profile (Shriberg, Kwiatkowski, & Rasmussen, 1990), a standardized prosody assessment, to study speech and prosody characteristics in individuals with HFA and individuals with Asperger syndrome (matched on age and verbal IQ [VIQ]) compared to a normative typical sample that was not matched on age, but was within the same age range. The authors found that some individuals with HFA used inappropriate phrasing, but that approximately half of the individuals with HFA were considered to have adequate prosody. Two studies using a sample of 32 children with HFA (McCann, Peppé, Gibbon, O'Hare, & Rutherford, 2007; Peppé, McCann, Gibbon, O'Hare, & Rutherford, 2007) measured prosodic deficits using the Profiling Elements of Prosodic Systems—Children (Peppé & McCann, 2003). Although this assessment was not standardized at the time of these studies, a sample of 72 children matched on verbal mental age was used for comparison. In contrast to Shriberg et al. (2001), the authors were able to find some evidence of deficits for each participant with autism in at least one area of prosody functioning. This prosodic assessment relied on human judgment of expressive prosody, and the authors highlighted the need for acoustic analyses in future studies to provide a fuller understanding of differences in expressive prosody.

Paul, Augustyn, and colleagues (2005) developed an experimental paradigm to measure expressive prosody. This study analyzed the profile of prosodic functioning in individuals with autism spectrum disorders (including 52% with HFA, 37% with Asperger syndrome, and 11% with a pervasive developmental disorder—not otherwise specified) in comparison to typical controls matched by age on a series of tasks designed to measure the comprehension and use of prosody for grammatical, pragmatic, and affective purposes. Paul, Augustyn, et al. (2005) found the participants with autism spectrum disorders showed impaired stress placement, but their use of intonation and phrasing was otherwise similar to typical controls.

Fine, Bartolucci, Ginsberg, and Szatmari (1991) used a trained phonetician to code the stress placement of individuals with HFA, individuals with Asperger syndrome matched on overall IQ and VIQ, and psychiatric outpatients (not matched on age, IQ, or verbal abilities) in a taped and unstructured 10-min interview. The authors found that participants with HFA were more likely than controls to misplace stress and to have unexpected patterns of stress placement with no communicative value. The authors also found more subtle deviations in stress placement between participants with Asperger syndrome and controls.

Overall, research using a wide variety of approaches (standardized assessments, and experimental paradigms, and coding by trained phoneticians) has had some success in the objective measurement of prosodic characteristics in HFA, although researchers have highlighted the importance of measures that may be more sensitive to subtle characteristics of prosody production in autism. In addition, research by Fine and colleagues (2001) shows that using naturalistic speech samples may reveal some of these more subtle differences. Paul, Augustyn, et al. (2005) and Peppé et al. (2007) have both highlighted the need for acoustic analyses to investigate the nature of these expressive impairments more explicitly.

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ACOUSTIC ANALYSIS OF PROSODY

The term prosody encompasses a number of suprasegmental aspects of speech, including metrical structure, phrasing, and variations in pitch level, or intonation. The acoustic measure of pitch is the fundamental frequency (F0). Pitch movements in English are of two types: "pitch accents," local peaks, or valleys in the F0 contour that align with prosodically prominent syllables; and boundary tones, which align with edges of phrases constituting major prosodic units. Both sorts convey pragmatic information. Patterns of relative prominence, with associated pitch accents, vary as a function of the information structure of the utterance, that is, the status of various constituents as discourse—new or given; boundary tones provide cues to the intended disposition of a sentence or phrase in discourse (Halliday, 1967; Ladd, 1980; Pierrehumbert & Hirschberg, 1990; among others). Individuals vary both in how much pitch movement they exhibit and in the range they employ in such movement. In addition, speakers can also mark information structure with changes in duration, changes in the intensity of the sound wave, or even changes in the segmental properties of a word. Nonetheless, less within-subject F0 variation than is typical might correlate with a less articulated metrical structure, with possible consequences for information structure. Alternatively, the same information may be marked but with less attention to pitch range (i.e., with lower or higher pitch peaks than is typical). Because pitch excursions above or below the typical range may be used to signal content specific to context, sustained production of this type of F0 variation would suggest that a speaker is using intonation in a nontypical manner, or is inattentive to pragmatic context.

An important gap in the current research on prosody production in autism is the lack of acoustic analyses of speech in this population. Shriberg and colleagues (2001) noted that the perceptual analysis of prosody may be inadequate to measure certain domains of prosodic functioning in this population. To our knowledge, only three studies have performed acoustic analyses of prosody on individuals with autism (Baltaxe, 1984; Fosnot & Jun, 1999; Paccia & Curcio, 1982), and none of these have focused exclusively on individuals with HFA. Paccia and Curcio (1982) showed the usefulness of this technique by showing how children with autism sometimes changed the prosody they heard when they echoed speech, indicating that echolalia sometimes serves more of a communicative function than often believed.

Two studies acoustically examined prosody in nonecholalic speech. Baltaxe (1984) tracked F0 in five individuals with autism (ages 4–12, ability level not specified) compared to children with language impairment and typically developing children matched on language level (mean length of utterances). Overall, children with autism and controls both had a wider frequency range than children with language impairment, but the children with autism appeared to have either very narrow or very wide ranges in F0. Fosnot and Jun (1999) found that four children with autism (ability level not specified) used a wider pitch range and had greater variation in F0 than age-matched typical controls or children who stuttered both when reading short sentences and imitating sentences produced by others.

These studies provide some initial indication of acoustic differences in the speech of children with autism, although there are several major gaps in the

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research. First, there is a need for analyses taken from larger samples of subjects to create findings that are more representative of the population. Second, it is necessary to measure F0 variation on a larger, more natural corpus of productive language data (e.g., such as a narrative or conversation). Third, it is important to understand further whether patterns of F0 variation tend to be wider (Baltaxe, 1984), or whether some individuals with autism have wider pitch range while others have a more narrow pitch range (Fosnot & Jun, 1999). In addition, there is a need for acoustic studies that match comparison groups on variables such as IQ and general language functioning to determine whether acoustic differences are specific to prosody or an artifact of more general language and/or intellectual functioning. Fourth and finally, the identification of acoustic properties of speech that can be measured by speech analysis software has potential for designing training programs that can detect prosodic differences acoustically and provide feedback to these individuals about performance (Kim, Newland, Paul, & Scassellati, 2008).

The purpose of the current studies is to use acoustic analyses to examine prosody production in children with HFA using larger sample sizes and a larger and more naturalistic speech sample (narratives). In both studies, we examine F0 range in speech samples taken from narratives to identify whether children and adolescents with HFA exhibit differences in pitch range in expressive prosody when compared to typically developing controls matched on intelligence and language abilities. Study 1 examined adolescents, and Study 2 was conducted in an attempt to replicate the findings from Study 1 in a different, and younger, sample of children.

STUDY 1

The first study examined the amount of within-subject variation in F0 in adolescents with HFA and typically developing controls matched on IQ and verbal abilities when retelling a cartoon they had just watched on television. Based on previous research on lower functioning individuals with autism, we predicted that children and adolescents with HFA would have more within-subject variation in their F0 than typically developing controls.

Method

Participants.

HFA GROUP. The participants were 21 children and adolescents with HFA between the ages of 10 and 18 years who were recruited from the community, a local hospital, and previous studies using this population (see Table 1 for descriptive characteristics of the sample). Diagnoses were confirmed with a combination of the Autism Diagnostic Interview—Revised (ADI-R; Rutter et al., 2003) with caregivers and the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 1999) with the participants. The ADOS and ADI-R provide cutoff scores for individuals considered to have an autism spectrum disorder. All participants met diagnostic criteria for an autism spectrum disorder on both the ADI-R and ADOS. Scores can also be used to make clinical diagnoses based on *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition, Text Revision* (*DSM-IV-TR*; American

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Table 1. *Descriptive characteristics of study samples*

	HFA Group	Control Group	F or χ^2	p
		Study 1		
N	21	21		
CA in years	13.58 (2.10)	13.24 (2.09)	.27	.61
Gender (M/F)	19:2	19:2	.00	1.00
PPVT-III	115.33 (12.52)	116.90 (13.10)	.16	.69
Wechsler				
Full-scale IQ	118.52 (14.73)	116.81 (13.43)	.16	.69
Verbal IQ	117.00 (14.10)	116.62 (12.54)	.01	.93
Performance IQ	116.05 (20.06)	112.76 (15.07)	.36	.55
		Study 2		
N	17	17		
CA in years	8.81 (2.13)	9.49 (2.22)	.92	.37
Gender (M/F)	13:4	12:5	.15	.70
CELF-3				
Total	101.53 (13.61)	101.59 (9.08)	.15	.99
Receptive	103.35 (16.26)	102.35 (10.47)	.21	.83
Expressive	100.47 (11.08)	102.12 (10.04)	.45	.65
SB-IV				
Composite (IQ)	104.00 (14.34)	107.71 (9.53)	.89	.38
Verbal reasoning	104.82 (20.15)	105.00 (9.14)	.03	.97

Note: CA, chronological age; PPVT-III, Peabody Picture Vocabulary Test, Third Edition; CELF-3, Clinical Evaluation of Language Fundamentals, Third Edition; SB-IV, Stanford Binet Intelligence Scale, Fourth Edition. Wechsler IQs were measured using the age-appropriate Wechsler measure (WISC-IV, WAIS-III). Values are means (standard deviations).

Psychiatric Association, 2000) criteria. All participants in this group met criteria for autistic disorder. It should be noted that no participants in Study 1 met *DSM-IV-TR* criteria for Asperger disorder.[1] Intellectual functioning was established using the Wechsler Intelligence Scale for Children, Third Edition (WISC-III; Wechsler, 1991) or the Wechsler Adult Intelligence Scale, Third Edition (WAIS-III; Wechsler, 1997). Language functioning level was determined using the Peabody Picture Vocabulary Test, Third Edition (PPVT-III; Dunn & Dunn, 1997) and the WISC-III or WAIS-III VIQ scores. In addition, all participants had full-scale IQ (FSIQ), VIQ, and PPVT-III scores greater than 80. It is important to note that, although children with autism may show some form of language delay/impairment in early development, many individuals on the high-functioning end of the autism spectrum have well-developed language abilities in late childhood/adolescence, and their communication impairment is primarily in the pragmatic use of language (Tager-Flusberg, Paul, & Lord, 2005; Young et al., 2005). Thus, children with HFA can achieve average to above average scores on standardized language measures and still

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exhibit pronounced social–communicative deficits (Siegel, Minshew, & Goldstein, 1996).

TYPICALLY DEVELOPING CONTROL GROUP. Twenty-one participants were recruited from the community. Participants were evaluated using the ADOS and either the ADI-R or the Autism Symptoms Questionnaire (Berument, Rutter, Lord, Pickles, & Bailey, 1999) to ensure that there were no indications of an autism spectrum disorder. All participants had FSIQ, VIQ, and PPVT-III scores greater than 80. There were no concerns about autism spectrum disorders, learning disabilities, mental retardation, language delays, or other psychiatric conditions in the control participants, and no history of autism spectrum disorders in their first- or second-degree relatives. Participants were matched by group on gender, age, FSIQ, VIQ, and PPVT-III total score to control for factors that could account for any observed differences. Intelligence was an important factor for us to control because we wanted to restrict our sample to individuals on the high-functioning end of the autism spectrum. We matched on verbal abilities (PPVT-III) to investigate what differences might be specific to prosodic deficits and not the result of impairments in general language abilities. Gender also was an important matching characteristic because females tend to have higher average pitch and more variation in F0 in their voice (see Henton, 1989, for a review).

Procedure.

NARRATIVE ELICITATION. Participants watched "Canary Row," a Sylvester and Tweety Bird cartoon that has previously been used to elicit narratives and gestures (McNeill, 1992). The cartoon depicts Sylvester trying to catch Tweety Bird across a series of attempts. The cartoon is primarily nonverbal, although there are a few short exclamations by characters. Participants saw the cartoon in three parts and retold the story after each part to someone they were told had not seen the cartoon before. Narratives were recorded with an external microphone on a stand near the participant that was connected to a VCR through an amplifier.

ACOUSTIC ANALYSES. Narratives were digitized and analyzed acoustically using Praat, a program for speech analysis and synthesis (Boersma & Weenink, 2005). We took a sample of average F0 from 250-ms time slices across the entire narrative (all three parts). This produced four data points per second. To determine if the populations differed in the extent to which they used intonation in their speech, we calculated the standard deviation in F0 for each subject. The standard deviation was calculated over all the measured samples of F0 in a subject. This is a basic measure of pitch range and has been used in other clinical acoustic research studies (e.g., Nilsonne, Sundberg, Ternström, & Askenfelt, 1988). For example, a relatively large average standard deviation would indicate an expanded pitch range. A relatively small average standard deviation would indicate more narrow pitch range. The average F0 across the entire narrative was also extracted. This provided a general characterization of pitch (e.g., high vs. low) to use as a

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Table 2. *Group means (standard deviations) and statistics for primary study variables*

	HFA Group	Control Group	F	p	η_p^2
Study 1					
Average *SD* across F0 samples	49.57 (9.81)	41.69 (12.49)	5.17	.03	.11
Average F0	189.95 (35.11)	173.57 (42.25)	1.87	.18	.05
Average number of clauses	73.48 (28.38)	95.52 (37.28)	4.65	.04	.10
Study 2					
Average *SD* across F0 samples	58.77 (16.46)	45.20 (13.15)	7.06	.01	.18
Average F0	212.25 (36.48)	207.84 (34.93)	0.13	.71	.004
Average number of clauses	23.47 (8.84)	28.94 (10.10)	2.82	.10	.08

Note: All F0 values are reported in Hertz. *SD*, average standard deviation of F0 across 250-ms samples.

baseline of pitch properties. A limited number of 250-ms segments were dropped because either the program could not get a pitch track, or the segments included listener and/or examiner comments. Because of the large number of segments per narrative, this did not affect analyses. We also correlated the standard deviation of F0 with the ADOS Communication factor score to relate findings to observed clinical communication deficits in participants with HFA. This factor score is calculated using an algorithm that is based on the *DSM-IV-TR* diagnostic criteria for the communication impairments in autism. ADOS scores are derived from a trained clinician's judgment of behaviors observed in a structured play session.

Results

Effect sizes were calculated as partial eta squared (η_p^2) to determine the degree of association between variables. Partial eta squared values between .01 and .06 are considered a small effect, between .06 and .14 are considered a medium effect, and above .14 are considered a large effect.

Overall, narratives ranged from 3 to 8 min long, and the group with HFA had significantly shorter narratives in terms of content (i.e., number of clauses; see Table 2). This difference, however, should not have an effect on subsequent statistics, because the overall length of the narratives gave a large number of 250-ms segments (range = 900–2,500 segments per narrative), which yielded a good representation of pitch movement for each subject. As expected, females in both groups (and overall) tended to have a higher average pitch for their voice and more variation in their F0 (see Table 3 for data by gender).

We used one-way analyses of variance to examine acoustic measures of speech (see Table 2 for means and statistical analyses). Overall, participants with HFA had a significantly greater average standard deviation across F0 samples than controls

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Table 3. *Group means for main variables by gender*

	HFA Group	Control Group	Total
Study 1			
Average *SD* across F0 samples			
Males	50.04 (10.13)	41.38 (13.12)	45.60 (12.41)
Females	45.16 (6.23)	54.08 (2.34)	49.63 (6.41)
Average F0			
Males	187.50 (35.43)	169.60 (44.25)	178.32 (40.69)
Females	213.22 (29.41)	183.74 (22.29)	198.48 (27.27)
Study 2			
Average *SD* across F0 samples			
Males	54.88 (13.58)	41.76 (12.63)	48.58 (14.50)
Females	71.44 (20.69)	53.46 (11.50)	61.45 (17.79)
Average F0			
Males	206.86 (35.61)	209.96 (35.70)	208.35 (34.94)
Females	229.78 (38.60)	202.77 (33.94)	214.76 (36.57)

Note: All F0 values are reported in Hertz. *SD*, average standard deviation of F0 across 250-ms samples.

(see Figure 1). This indicates that participants with HFA had a wider F0 range in their narratives. The groups were not significantly different in the average pitch of their narratives.

For the HFA group, the ADOS Communication factor score (mean = 4.4, *SD* = 1.7) was significantly correlated with the average standard deviation across F0 samples, r (20) = .43, $p < .05$. Specifically, subjects with HFA with higher variation in their intonation tended to be judged by a trained clinician as having a greater level of communication impairment. Similar comparisons were not done with the control group, because the majority of these subjects had scores of 0 on the ADOS Communication Scale (mean = 0.23, *SD* = 0.44).

Conclusions

As predicted, the narratives of children and adolescents with HFA had more within-subject variation in their prosody than typical controls, and this finding was related to clinical judgments of communication impairment in HFA. The findings are not conclusive, however, because there was considerable overlap in the standard deviation of F0 variation between the groups, suggesting that the use of the standard deviation of F0 alone as a measure may not capture fully all of the acoustic factors that could contribute to atypical expressive prosody. Both groups had relatively high cognitive abilities, so it is important to examine these findings with participants who are closer to the average range of intellectual functioning to see whether these findings are generalizable to a broader range of individuals with HFA. In addition, because participants included adolescents, it is possible that differences in expressive prosody could be masked because of additional social experience gained through intervention or more exposure to social interaction.

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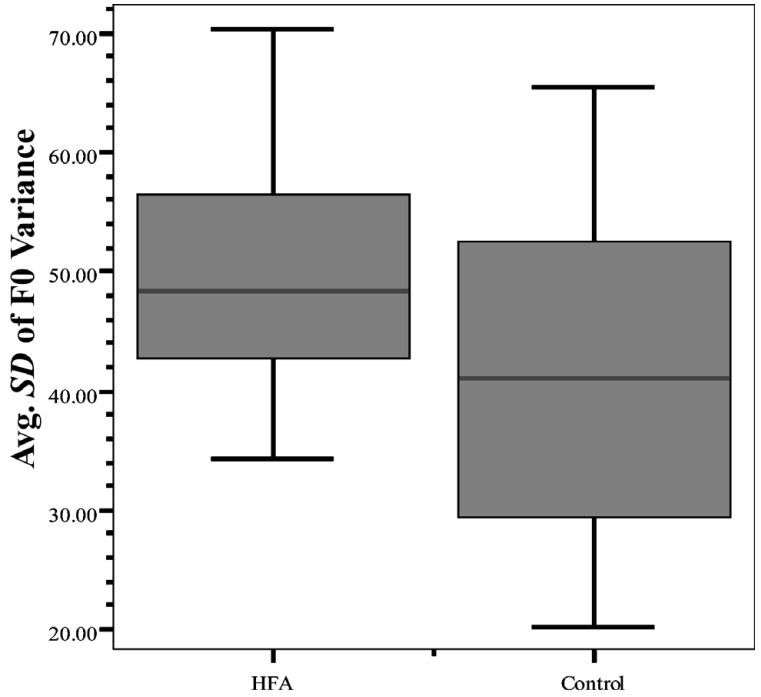


Figure 1. Group differences in the standard deviation of the fundamental frequency (F0) in Study 1. *Note:* The box plot represents each group's median and 95% of the range of the standard deviations of F0 (Hz).

Moreover, it is possible that the higher (although not significant) average F0 of the HFA group accounted for observed differences, as people with higher pitched voices tend to have greater variation in F0 (Henton, 1989).

STUDY 2

This study was designed to replicate and extend the findings of Study 1 in a population of children with HFA who were younger and did not have IQs that were as high as those in Study 1, although the IQs for this study were still predominantly in the normal range of cognitive functioning. This sample had the additional advantage of expressive and receptive language data to match on overall language abilities, and not just receptive vocabulary. This matching procedure provides a more rigorous test of whether differences might be specific to prosodic deficits and not the result of impairments in general language abilities. Based on previous clinical accounts and the findings of Study 1, we predicted that there would be greater within-subject variation in the intonation of children with HFA than typical controls when analyzed acoustically. We also predicted there would be no group differences in the more general measure of average pitch.

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Methods

Participants.

HFA GROUP. The group with HFA was composed of 17 children between the ages of 6 and 14 (see Table 1). Diagnoses were established as above with both the ADOS and the ADI-R, along with clinical judgment by a developmental pediatrician and/or psychologist. All participants met criteria for an autism spectrum disorder on both the ADOS and ADI-R. Fifteen of the 17 participants met *DSM-IV-TR* criteria for autistic disorder, and the remaining two participants met criteria for Asperger syndrome. Because of potential differences in prosodic functioning between Asperger syndrome and HFA (Ghaziuddin & Gerstein, 1996), results were analyzed with and without these two participants. Intellectual functioning was determined using the Stanford Binet Intelligence Scale, Fourth Edition (SB-IV; Thorndike, Hager, & Sattler, 1986). Language functioning was determined via the Clinical Evaluation of Language Fundamentals, Third Edition (CELF-3; Semel, Wiig, & Secord, 1995). Similar to Study 1, all participants had SB-IV test composite, SB-IV verbal reasoning, and CELF-3 receptive, expressive, and total scores higher than 80.

TYPICALLY DEVELOPING CONTROL GROUP. Seventeen typically developing children were recruited from the community and evaluated as described above. The presence of any autism spectrum disorder was ruled out using the ADOS and the ADI-R. There were also no concerns about any autism spectrum disorder, learning disabilities, mental retardation, language delays, or other psychiatric conditions in the participants, and no history of autism spectrum disorders in their first- or second-degree relatives. Control participants were matched to the HFA sample by group on age, gender, expressive and receptive language standard scores from the CELF-3 and the test composite and verbal reasoning subscale of the SB-IV. These participants were also used in studies looking at the psychometric evaluation of pragmatic language (Young et al., 2005) and narrative performance (Diehl, Bennetto, & Young, 2006).

Procedures.

NARRATIVE ELICITATION. Participants listened to an audiotaped verbal narration of the story *Frog, Where Are You?* (Mayer, 1969) while looking at a wordless picture book. The story is about boy whose pet frog has escaped from his jar. The boy and his dog go through a series of mishaps before finding the frog, which now has a frog family. The examiner left the room while the participants listened to the story, but said they wanted the participant to tell them the story when they returned without looking at the pictures. Subjects were recorded using a hand-held tape recorder and videotaped using a VHS camcorder with an internal microphone. Acoustic analyses were performed as described in Study 1. It should be noted that the elicitation method in Study 2 differed from Study 1. Whereas Study 2 involved listening to the verbal narration of a story, Study 1 had virtually no verbal information that accompanied the actions of the characters.

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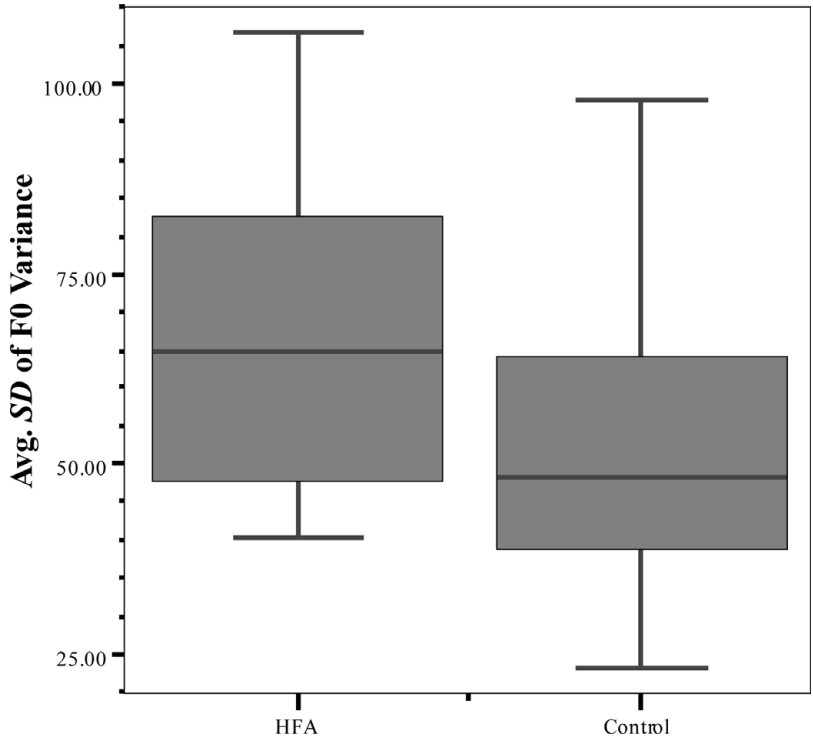


Figure 2. Group differences in the standard deviation of the fundamental frequency (F0) in Study 2. *Note:* The box plot represents each group's median and 95% of the range of the standard deviations of F0 (Hz).

Results

Effect sizes were determined as described in Study 1. Overall, narratives ranged from 1 to 4 min long, and there was a trend for the group with HFA to have longer narratives (see Table 2). Similar to Study 1, female subjects tended to have a higher average pitch in their voice and had more variation in their F0 (see Table 3). Moreover, this younger sample had a higher overall pitch for their voice and more variation in their F0 than did the older sample from Study 2. These findings provide support for the validity of our measurements, as females (Henton, 1989) and younger children (Whiteside & Hodgson, 2000) would be expected to have a higher overall pitch and more variation in their F0 for these types of analyses.

One-way analyses of variance revealed that the HFA group had significantly greater average within-subject standard deviation across F0 samples than typical controls (see Figure 2), but groups were not significantly different in average pitch (see Table 2 for statistics). As predicted, these findings indicate that this group had greater within-subject variation in the intonation patterns of their narratives that cannot be accounted for by differences in average pitch. Unlike Study 1, ADOS Communication factor scores (mean = 2.71, SD = 1.1) were not significantly

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related to the average standard deviation across F0 samples, r (16) = .06, p = .83. The mean of the control group on the ADOS Communication factor was 0.18 (SD = 0.39), and as in Study 1, we did not run correlations with this variable.

The two subjects diagnosed with Asperger syndrome had average standard deviations across F0 samples of 79.3 and 47.3 Hz, respectively. It is difficult to draw conclusions about this subgroup with only two subjects. Overall findings, however, were similar regardless of whether or not the two children with Asperger syndrome were included in the HFA group.

Conclusions

This study replicates and extends the findings of Study 1 by showing that individuals with HFA exhibit a wider F0 range in their prosody even when matched on language in addition to cognitive abilities. Study 2 also extends the research to a younger population of individuals with HFA, who also have IQ scores that are closer to the average range of the general population than those in Study 1. Importantly, both groups had identical F0 averages in Study 2, suggesting that observed within-subject differences in F0 variation are not the result of between-group differences in average pitch. It is still unclear, however, whether the acoustic findings of these two studies are analogous to human perception of prosody, or whether acoustic analyses of individuals with HFA measure subtle group differences that are not perceived by listeners.

Study 1 suggested a relationship between acoustic data and clinician judgments of communication, but Study 2 failed to replicate this finding. It is possible that the small amount of variance in ADOS Communication Factor scores in Study 2 (SD = 1.1) limited our ability to detect correlations between the two measures. It is also possible that intonation carries greater weight for clinical judgments of communication impairment for older individuals with HFA (Study 1) than for younger individuals (Study 2). It may be that expressive prosodic difficulties in autism are independent of other communicative deficits in autism. Future studies should include qualitative measures of expressive prosody that could be used as dependent variables that are more sensitive to individual differences.

It is also important to note that while both Study 1 and Study 2 involved the retelling of a story, the elicitation methods differed. In Study 1, participants retold a story from a cartoon with no narration, and in Study 2 participants listened to a verbal narration of a story accompanied by a picture book. The act of listening to a story before retelling it, such as in Study 2, could provide a template for the prosody of storytelling that might affect the results. It is possible that providing a prosodic template leads to more overlap in F0 variation between groups. Still, even with different elicitation techniques, both studies had similar findings across acoustic measures and were able to find between-group differences in F0 variation.

GENERAL DISCUSSION

The current series of studies provide support for the use of acoustic measurements as a valid, objective measure of the perceived deficits in expressive prosody in autism. Previous research on autism has not consistently identified the prosodic

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deficits that are reported clinically, and studies using acoustic measures have had small sample sizes and have not focused specifically on the higher functioning end of the autism spectrum. This study examined children with HFA, a subgroup of individuals with autism spectrum disorders who have normal intelligence and relatively well-developed linguistic abilities. Study 1 found that adolescents with HFA had more within-subject F0 variation in their narratives than controls. Study 2 extended these findings to a different sample of younger children with HFA who had slightly lower IQ scores than Study 1. In addition, Study 1 found evidence that acoustic measurements of prosody were related to clinical judgments of autism-specific communication impairments. Although this was not replicated in Study 2, it is possible that the small amount of variance in the ADOS Communication factor scores in Study 2 ($SD = 1.1$) could account for a failure to find a correlation between these variables.

The findings of increased F0 variation in individuals with HFA is consistent with previous studies with lower functioning individuals with autism (Baltaxe, 1984; Fosnot & Jun, 1999), although Fosnot and Jun found both high and low F0 variation in their sample. It should be noted that there was significant overlap between our HFA and control groups in F0 variation, suggesting the possibility that not all individuals with HFA exhibit intonation patterns that are different from their peers. Other studies also demonstrated that there does not seem to be a specific aspect of prosody (e.g., intonation pattern or phrasing) that is disrupted in all individuals with autism (McCann et al., 2007; Peppé et al., 2007; Shriberg et al., 2001), although Peppé and colleagues (2007) did find that at least one aspect of prosodic usage was disordered in all of their participants.

The relationship of expressive prosody to communication deficits in autism

This study provides evidence that there are characteristics of speech that differentiate prosody in individuals with autism from normal prosody production, and that these differences can be quantified and measured acoustically. An important question raised by these findings is why a particular child with HFA might have more variation in their F0 than their language-matched typical peers. The amount of within-subject variation in F0 decreases with age in typical development (Whiteside & Hodgson, 2000), so it is possible that the difference in F0 variation between the HFA and control group is due to a relative delay in this aspect of prosody use in language/communication development. In other words, it is possible that individuals with HFA eventually develop the same F0 variation as controls, but this happens at a later age. This would signal delayed, rather than deviant development. It is interesting that group differences were greater between the younger HFA and control groups (Study 2) than in the older groups (Study 1). Because the groups were matched on language abilities, however, one might expect that developmental differences would be eliminated. Thus, more variable prosody may be a function of a general delay in later developing communication abilities.

It is also plausible that the increased within-subject F0 variation underlies the subtle idiosyncrasies that distinguish the speech of individuals with HFA. Greater F0 variation could suggest that a speaker is placing discourse marking on more information than is typical, or that they are marking the same information but

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with greater intensity. This interpretation must be viewed with caution, however, because there is some evidence that greater F0 variation may not be specific to HFA. A recent study of children with Williams syndrome (WS) also found increased F0 variance, although it is possible the differences in this study could be accounted for by the higher average pitch of the WS group (Setter, Stojanovik, Ewijk, & Moreland, 2007). Of interest, Setter and colleagues also found that their participants with WS were more emotionally involved in their story telling task, and that this emotional involvement was strongly correlated with their pitch range. This stands in stark contrast to narrative studies on children with autism, which have shown that their narratives are deficient in measures of narrative engagement (e.g., Capps, Losh, & Thurber, 2000). Therefore, it is possible that there are different factors influencing pitch variance in autism and WS. Further insight into this question may come from individuals with speech and language disorders not related to autism, who also show subtle atypicalities in prosody use (e.g., Wells & Peppé, 2003). Future studies should compare the standard deviations of F0 (along with other prosody categories) within and between these groups to identify acoustic profiles of prosodic functioning that are specific to each group.

Our study used gross acoustic measurements across the length of a narrative to investigate the sensitivity of this method. By nature, narratives differ from person to person in their length, content, and manner of retelling, which makes it difficult to make acoustic comparisons of specific aspects of prosody (e.g., stress, phrasing, among many others) between groups. For example, characteristics such as pausing to recall a forgotten portion of a narrative, and the tendency for no two participants to remember and structure their narratives the same way, makes it difficult to examine acoustically the use of phrasing in a group of narratives. To understand further the acoustic characteristics of prosody in this population, it will be important to use speech content that is standardized across subjects to examine within-subject F0 variation in the context of its structure and function in a sentence. Standardized speech content is not spontaneous, however, which would limit its ecological validity to some extent. Therefore, it would be useful to collect both spontaneous speech (e.g., from narratives) and standardized speech samples in future studies to have one set of data that is more ecologically valid, and another that is more reliably similar in content across participants.

Limitations and directions of future research

These studies reinforce assertions that there is a pressing need for researching prosody in autism with more sophisticated methods such as acoustic analyses (Paul, Augustyn, et al., 2005; Peppé et al., 2007). This study highlighted the utility and sensitivity of acoustic analysis as a measure of prosodic functioning in HFA. Future research should use this technology to focus on the use of prosody to express, emphasize, or alter meaning of the accompanying words. In addition, future studies should examine other characteristics of prosody, such as its metrical structure and the use of pauses to communicate.

Another important question is the relationship between heterogeneity of prosodic atypicalities and the broad spectrum of communication deficits in autism spectrum disorders. For example, both Ghaziuddin and Gerstein (1996) and

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Eisenmajer and colleagues (1996) found that characteristics of prosody differentiate Asperger syndrome from HFA. Two participants in Study 2 met diagnostic criteria for Asperger syndrome, and the small number of participants in this group did not allow for statistical comparison. One major obstacle in pursuing this line of research is that the diagnosis of Asperger syndrome is an area of considerable disagreement (Volkmar et al., 2004). There are as many as six existing definitions of Asperger syndrome being used in the literature, and studies have suggested that current frameworks do not create reliable categorical differentiations (Howlin, 2003; Miller & Ozonoff, 2000; Volkmar et al., 2004). Because of the high current level of general language functioning of our population, it is likely that some of our children could have met criteria for Asperger syndrome using other definitions, especially systems that refer to Asperger syndrome simply as a milder form of autism (Leekam, Libby, Wing, Gould, & Gillberg, 2000). Still, because of the wide range of prosodic deficits, examining their relationship to subgroups of autism spectrum disorders could provide insight into the nature and etiology of the spectrum of autistic disorders.

It is important to note that this paper focuses exclusively on prosody production. McCann and Peppé (2003) emphasize the need for understanding prosody comprehension in addition to differences in prosodic expression in individuals with HFA. Several recent studies have begun to address this question (e.g., McCann et al., 2007; Paul, Augustyn, et al., 2005; Peppé et al., 2007; Rutherford, Baron-Cohen, & Wheelwright, 2002), but there is still much to be learned about prosody comprehension in this population. Because language comprehension often precedes production in development, it is important to investigate comprehension abilities further to truly understand the nature of differences in prosody use.

Clinical implications

These studies are important for several reasons. By utilizing acoustic measures of prosodic ability/disability that can be measured by publicly accessible speech analysis software, this methodology can be used to investigate outcomes of treatment. This approach is already being used to measure the effects of pharmacological agents on symptoms of depression, as these individuals tend to show decreased F0 variance during a major depressive episode (Alpert, Pouget, & Silva, 2001; Garcia-Toro, Talavera, Saiz-Ruiz, & Gonzalez, 2000). Moreover, it may be possible to develop therapeutic programs for individuals with prosody deficits. For example, a program could be developed that acoustically analyzes the prosody of individuals with autism, and provide immediate feedback to an individual on their prosody patterns. In fact, Kim and colleagues are currently developing such a program for use with children with autism (Kim et al., 2008).

Abnormalities in intonation are considered a characteristic of the disorder according to the *DSM-IV-TR* and are measured in standardized diagnostic assessments like the ADOS and ADI-R. Increased analysis at the acoustic level will allow researchers to better refine what is known about deficits in this population and allow test makers to develop measures that are sensitive to the specific profile of prosodic functioning in HFA. These findings highlight the presence of these atypicalities even in very high-functioning and linguistically developed

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adolescents and emphasize the need for diagnostic attention to prosody in a subgroup where subtle yet clinically significant impairments in social–communication drive diagnoses and can be a stigmatizing barrier to social acceptance (Shriberg et al., 2001).

In summary, this series of studies shows the usefulness of acoustic measures in examining prosody functioning in this population. It also highlights the powerful potential of using acoustic and perceptual analyses together to understand clinical communication impairment. Finally, these findings provide a basis for future areas of research on prosodic expression in HFA.

ACKNOWLEDGMENTS

We thank Dr. Edna Carter-Young for her assistance in the acquisition and analysis of a subset of the narratives used in this study. We are also grateful to the children and families who participated in this research. This study was supported in part by NIH Grant PO1 HD35466 (a Collaborative Program of Excellence in Autism) and by NIH General Clinical Research Center Grant NCRR 5MO1 RR00044 from the National Center for Research Resources.

NOTE

1. According to *DSM-IV-TR* criteria, autistic disorder may include a delay in the acquisition of early language milestones (e.g., spoken words by 18 months, phrases by 24 months) among other defining characteristics, whereas no such language delay may be present for a diagnosis of Asperger disorder. A delay in language development, however, is not necessary for a diagnosis of autistic disorder.

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