Fundamental Frequency and Intensity Mean and Variability Before and After Two Behavioral Treatments for Aprosodia

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Emerging data suggest that aprosodia may be amenable to behavioral treatment. This study investigated the use of acoustic analysis of speech to quantify response to two speech treatments previously judged to have an effect based on perceptual assessment in three participants with primarily expressive aprosodia. The mean and variability of fundamental frequency (F0) and intensity (INT) during production of sentences requiring use of four different emotional tones of speech (i.e., happy, angry, sad, or neutral) was calculated before and after two mechanism-based treatments for aprosodia (i.e., TX1 and TX2). Statistical differences in F0 mean and variability were primarily observed following TX1, whereas differences in INT mean and variability were principally revealed following TX2. Additionally, significant differences in these acoustic values were noted across almost all pairwise comparisons of emotional sentence types (i.e., angry vs. sad,

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happy vs. sad, neutral vs. sad, angry vs. neutral, and happy vs. neutral). These preliminary data suggest that perceptual improvements in aprosodia can be measured quantitatively using acoustic analysis of speech and provide additional support for previously described behavioral treatments for this disorder. These findings also support previous reports that suggest that different emotional tones of speech are associated with differences in the acoustic speech signal.

Prosody can be defined as the suprasegmental features of speech conveyed perceptually by pitch, stress, and duration. These features have also been defined acoustically primarily as changes in fundamental frequency (F0), intensity (INT), and timing (Kent & Read, 2002; Kent, Weismer, Kent, Vorperian, & Duffy, 1999; Lehiste, 1970; Pell 1999). Prosody has been described as having both linguistic and affective components (Heilman, Leon, and Rosenbek, 2004; Pell, 1999). Linguistic prosody serves to clarify word and sentence types and affective (or emotional) prosody is used to express a speaker's emotions and attitudes (Myers, 1999). Traditionally, the left hemisphere has been assigned the major role in controlling linguistic prosody and the right hemisphere in controlling affective prosody, though this has been viewed by some as an oversimplification (Pell, 1999). Abnormalities in affective prosody have been described as expressive (Tucker, Watson, & Heilman, 1977) or receptive in nature (Heilman, Scholes, & Watson, 1975). Ross (1981; see also Ross & Monnot, 2008) suggested that affective prosodic deficits associated with right hemisphere lesions be called aprosodia and posited specific types that mirror the traditional aphasia types.

The effect of aprosodia on functional status has prompted growing interest in behavioral treatments, as reflected in several studies (Anderson, Beversdorf, Heilman, & Gonzalez-Rothi, 1999; Leon et al., 2005; Rosenbek et al., 2004; Stringer, 1996). Most recently, Rosenbek et al. (2006) administered two randomly ordered conceptual treatments, one imitative and one cognitive-linguistic, to 14 individuals with primarily expressive aprosodia after right-hemisphere stroke. The imitative program was motivated by the hypothesis that expressive aprosodia results from impaired motor programming/planning of the vocal elements that constitute emotional prosody (van der Merwe, 1997), whereas the cognitive-linguistic approach was motivated by the hypothesis that aprosodia results from a deficit in a modality specific nonverbal affect lexicon (Bowers, Bauer, & Heilman, 1993).

An ABAC single-subject design replicated across subjects was employed. Probes of treated and untreated emotions were administered during baseline and treatment phases, and these probe items were then perceptually judged by a trained rater blinded to the testing condition. These data were used to perform visual inspection and determine effect size. Visual inspection of the data was completed by three judges experienced in using this technique. For these 14 participants, visual analysis indicated a treatment effect for 18 out of 25 total treatments (three patients did not have the second treatment) and significant effect sizes ($z \geq 2.00$) were noted in 11 out of 25 total treatments.

Acoustic analysis of speech is being increasingly used in the study of affective prosody (Banse & Scherer, 1996; Erickson et al., 2006; Gandour, Larsen, Dechongkit, Ponglorpisit, & Khunadorn, 1995; Hammerschmidt & Jurgens, 2007; Kent & Rosenbek, 1982; Monnot, Orbello, Riccardo, Sikka, & Ross, 2003; Pell 1999; Pell & Baum, 1997; Scherer, 1986; Van Lancker & Sidtis, 1992). Right hemisphere lesions have been found to be associated with aberrant measures of F0, intensity, and timing at the sentence level (Gandour et al., 1995). Additionally, the notion that F0, particularly its variation, is "of primary importance in distinguishing affective meanings" (Pell & Baum, 1997, p. 208) has been supported by a number of previous acoustic studies of emotional prosody (Monnot et al., 2003; Pell, 1999; Ross & Monnot, 2008; Scherer, 1986; Van Lancker & Sidtis, 1992).

The primary purpose of the present study was to determine if F0 mean and variability, as well as INT mean and variability, changed in three individuals who received behavioral treatments perceptually judged to have an effect. We predicted that F0 mean and variability would be significantly different before and after treatment due to the beneficial effects of intervention and the primacy of F0 in conveying affective prosody. Differences in INT mean and variation were also predicted, but these were expected to be less substantial due to the lesser contribution of INT in conveying emotional prosody. We expected these differences to be most pronounced following the first of the two treatments, as Rosenbek et al. (2006) reported a larger effect size for these three participants based on perceptual assessment following the first treatment (TX1) in comparison to the second treatment (TX2).

Our secondary purpose was to determine whether F0 and INT mean and variability were significantly different across the tested emotional tones of speech (i.e., happy, sad, angry, and neutral). Due to the critical contribution of F0 and its variance to affective prosody, we predicted that pairwise comparisons between emotions would reveal significant differences in F0 mean and variability across emotions. The effect on INT mean and variability across compared emotions was expected to be less robust due to the lesser contributions of these parameters on affective prosody.

METHODS

Subjects

Three participants from a larger group of 14 subjects (Rosenbek et al., 2006) were selected based on the availability of high quality digital recordings that allowed for acoustical analysis, and the presence of an effect for both treatments based on perceptual assessment and resultant statistical and visual analyses.

The three participants, two women and one man, were right handed, native English speakers who suffered right cerebral hemisphere strokes with resultant expressive greater than receptive aprosodia. Table 1 provides a listing of relevant descriptive information for all three subjects, as well as effect size data for each of the treatments (z-score ≥ 2.00 considered significant). Visual analyses revealed a positive treatment effect for all three of the participants by all three trained raters following both of the treatments.

Experimental Design

An ABAC single subject design replicated across subjects was utilized with two randomly ordered treatments. Both treatments were administered over a 1-month period and were separated by a 1-month nontreatment phase (i.e., the second A phase). Acoustic recordings of speech were made during administration of the main outcome measure during eight sessions: twice during each of two baseline phases and twice during each of two posttest sessions. Posttest measures were obtained over two sessions immediately following each of the two treatments. This measure required subjects to produce emotionally congruent sentences using the targeted emotional tones of happy, sad, angry, and neutral speech.

Procedures

Productions of sentences using emotional tones of speech were recorded using a digital audio tape recorder (Tascam DA-P1) and a high-quality head-mounted microphone (Shure SM10A) positioned two centimeters from the left corner of the mouth. Recordings were transferred to a PC at a sampling rate of 22050 Hz using a 16-bit sound card and then analyzed using TF32 software (Milenkovic, 2001) to measure F0 and INT mean and standard deviation (SD). A total of 838 sentences were recorded and analyzed (239 angry sentences, 237 happy sentences, 240 sad sentences, and 122 emotionally neutral sentences).

Dependent Variables

Dependent variables included F0 mean, F0 variability, INT mean, and INT variability. Variability for F0 was determined using the coefficient of variation (CV), defined as the ratio of the standard deviation to the mean multiplying by 100. Two additional measures of variability were also calculated [(i.e., log(SD) and log(range)]. INT data were measured in relative rather than absolute values and, therefore, microphone placements and recording levels were held constant within and across testing sessions for each speaker. INT was measured using a dB scale relative to the power of a 5 volt signal. Since the mean INT measure is relative and can be influenced by the reference level, we chose to measure INT variability using the log(SD) rather than the CV. In the analysis, log transformation was applied.

Data Analysis

Regression analyses were completed to analyze the mean and variability of F0 and INT across three independent factors: participant (1, 2, or 3), emotion (happy, angry, sad, or neutral), and treatment (TX1 or TX2). Least-squares means tests were computed for both TX1 and TX2 for F0 and INT to determine the overall effect associated with

TABLE 1. Subject demographics and effect sizes based on perceptual assessment.

Subject	Age	Gender	Education Level	Occupation	Depression Medications	Duration Post Onset	Lesion Localization	TX1 Z-Score	TX2 Z-Score
1	83	F	12	Homemaker	None	2 years	Right hemisphere cortical and subcortical structures, frontal parietal, and temporal involvement	3.02*	0.62
2	57	F	13	Healthcare professional	Zoloft 50 mg/day	9 months	Right hemisphere, parietal infarct with posterior temporal and posterior frontal involvement	3.68*	2.76*
3	55	M	AS	Medical technology	Remeron 30 mg/day	1 year	Right MCA, basal ganglia, and temporal parietal cortex involvement	4.15*	0.99

*indicates a statistically significant effect size (z-score ≥ 2.00); AS = Associate of Science each treatment. All p-values to determine statistical significance were set the 0.05 level.

RESULTS

Summary statistics for F0 and INT before and after TX1 and TX2 are found in Table 2. Table 3 shows the results of the F0 regression analysis and least squares means estimates. mean F0 was found to be significantly increased following TX1 ($p < .0001$) but was unchanged following TX2 ($p = 0.35$). Pairwise comparisons of mean F0 across all emotions and testing sessions (i.e., all baseline and posttest sessions) revealed statistically significant differences across all paired comparisons. That is, increases in mean F0 were observed in angry vs. sad speech ($p < .0001$), happy vs. sad speech ($p < .0001$), neutral vs. sad speech ($p < .0001$), angry vs. neutral speech ($p < .0001$), happy vs. neutral speech ($p < .0001$), and angry vs. happy speech ($p < .0001$).

F0 variability, as measured by the CV, was significantly increased following TX1 ($p < .0001$) but was statistically unchanged after TX2 ($p = 0.06$). Other measures of variability revealed similar results. For example, following TX1, significant increases in the log(SD) ($p < .0001$) and the log(range) ($p < .0001$) of F0 were measured. After TX2, no difference in log(range) ($p = 0.89$) of mean F0 was found, though log(SD) did increase significantly ($p = 0.03$). Pairwise comparisons of F0 variability across emotions and testing sessions using the CV revealed statistically significant increases in F0 variability between angry vs. sad speech ($p < .0001$), happy vs. sad speech ($p < .0001$), angry vs. neutral speech ($p = 0.003$), happy vs. neutral speech ($p < .0001$), and angry vs. happy speech ($p < .0001$). Significant differences between these emotions were also found by the log(SD) and the log(range). The CV revealed no difference in F0 variability between neutral and sad speech, though increased variability in neutral vs. sad speech was suggested by the log(SD).

Table 4 shows the results of the INT regression analysis and least squares means tests. Mean INT was found to be significantly increased following TX1 ($p < .0001$) and decreased following TX2 ($p = 0.03$). Pairwise comparisons across emotions and testing sessions revealed statistically significant increases in mean INT between angry vs. sad speech ($p < .0001$), happy vs. sad speech ($p < .0001$), neutral vs. sad speech ($p = 0.03$), angry vs. neutral speech ($p < .0001$), and happy vs. neutral speech ($p < .0001$). No difference in mean INT was found between angry and happy speech ($p = 0.03$).

INT variability, as measured by the log(SD),was unchanged following TX1 ($p = 0.25$) but was increased following TX2 ($p = < .01$). Similar to the log(SD) findings, measurement of INT variabili-

TABLE 2. Summary statistics. All F0 measurements are in Hz and INT measurements are in DB, except for CV data. CV is a ratio and does not have units of measure. INT was measured using a dB scale relative to the power of a 5 volt signal.

	Baseline 1		Baseline 2		Posttest 1		Posttest 2	
Dependent Variable	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
F0 mean (Hz)	169.3	33.4	184.4	39.9	183.3	43.5	186.3	53.0
F0 minimum (Hz)	88.1	33.5	90.7	35.5	100.7	38.3	97.4	41.4
F0 maximum (Hz)	240.1	57.9	288.9	109.2	283.8	89.5	299.1	158.2
F0 variability – CV	16.8	6.8	21.0	11.3	21.6	12.4	22.5	10.0
INT mean (dB)	63.8	13.0	68.1	8.1	66.7	6.2	66.7	6.2
INT minimum (dB)	30.1	11.3	35.1	9.6	35.4	7.4	30.1	9.0
INT maximum (dB)	79.1	11.1	85.2	6.7	83.6	4.9	83.5	7.2
INT variability – (SD)	10.7	2.3	11.4	3.2	10.8	1.8	12.0	2.4

SD = Standard deviation, F0 = fundamental frequency, Hz = hertz, INT = intensity, dB = decibels, SD = standard deviation, CV = coefficient of variation

TABLE 3. Regression analysis and least squares means tests for F0.

		F0					
		CV			Mean		
		Effect Estimates	SE	p–Value for CV	Effect Estimates	SE	p–Value
Intercept		24.84	0.82	<.0001*†‡	121.54	2.25	<.0001*
Emotion	A vs. S	3.98	0.75	<.0001*†‡	36.72	2.40	<.0001*
	H vs. S	10.59	0.75	<.0001*†‡	47.89	2.04	<.0001*
	N vs. S	1.27	0.91	0.16†	10.87	2.48	<.0001*
	A vs. N	2.71	0.91	0.003*†‡	25.86	2.48	<.0001*
	H vs. N	9.32	0.91	<.0001*†‡	37.02	2.48	<.0001*
	A vs. H	–6.61	0.75	<.0001*†‡	–11.17	2.04	<.0001*
Treatment	TX1 vs. TX2	–1.00	0.80	0.21†	–3.16	2.18	0.15
Patient	1 vs. 3	–9.25	0.69	<.0001*‡	41.43	1.89	<.0001*
	2 vs. 3	–10.61	0.70	<.0001*	76.18	1.89	<.0001*
	1 vs. 2	1.35	0.69	0.05	–34.75	1.89	<.0001*
LS–Mean (TX1)		4.73	0.80	<.0001*†‡	14.04	2.18	<.0001*
LS–Mean (TX2)		1.50	0.80	0.06†	2.06	2.18	0.34

* = Statistically significant at the 0.05 level for F0 variability (as measured by CV) or mean

† = Statistically significant at the 0.05 level for F0 variability or mean as measured by log(SD)

‡ = Statistically significant at the 0.05 level for F0 variability or mean as measured by log(range)

F0 = fundamental frequency, CV = coefficient of variation, SE = standard error, A = angry, S = sad, H = happy, N = neutral, TX1 = treatment 1, TX2 = treatment 2, LS = least squares

ty with the log(range) revealed statistically significant increases after TX2 ($p < .0001$) but not after TX1 ($p = 0.19$). Pairwise comparisons of INT variability across emotions and testing sessions using the log(SD) revealed statistically significant increases in INT variability between angry vs. sad speech ($p < .0001$), happy vs. sad speech ($p < .0001$), neutral vs. sad speech ($p < .004$), angry vs. neutral speech ($p < .0001$), and angry vs. happy speech ($p = 0.0003$). Results of the log(range) comparison were consistent with these findings, except for a lack of significant difference between neutral and sad speech ($p = 0.24$) with this measure. No difference in INT variability using the log(SD) ($p = 0.40$) or the log(range) ($p = 0.20$) was found between happy and neutral speech.

DISCUSSION

The primary purpose of this study was to determine if F0 mean and variability, as well as INT mean and variability, changed systematically with behavioral treatments perceptually judged to have an effect. Due to the critical contribution of F0 to affective prosody, we predicted that F0 mean and variability would differ before and after treatment due to the effects of intervention. We expected this effect would be greater with TX1, as the effect size data from perceptual analysis was greater for these three participants with TX1 than with TX2. However, results of the least squares means estimate indicate that both TX1 and TX2 were associated with statistically significant changes in the prima-

TABLE 4. Regression analysis and least squares means tests for INT.

		INT					
		Log(SD)			Mean		
		Effect Estimates	SE	p–Value for Log(SD)	Effect Estimates	SE	p–Value
Intercept		2.45	0.02	<.0001†‡	56.13	0.67	<.0001*
Emotion	A vs. S	0.14	0.02	<.0001†‡	6.11	0.61	<.0001*
	H vs. S	0.08	0.02	<.0001†‡	5.58	0.61	<.0001*
	N vs. S	0.06	0.02	<.004†	1.60	0.74	0.03*
	A vs. N	0.08	0.02	0.0001†‡	4.51	0.74	<.0001*
	H vs. N	0.06	0.02	0.40	3.98	0.74	<.0001*
	A vs. H	0.06	0.02	0.0003†‡	0.53	0.61	0.39
Treatment	TX1 vs. TX2	–0.10	0.02	<.0001†‡	1.72	0.65	0.01*
Patient	1 vs. 3	–0.17	0.02	<.0001†‡	11.20	0.57	<.0001*
	2 vs. 3	0.01	0.02	0.43‡	9.83	0.57	<.0001*
	1 vs. 2	–0.18	0.02	<.0001†‡	1.37	0.57	0.02*
LS–Mean (TX1)		0.02	0.02	0.25	4.68	0.65	<.0001*
LS–Mean (TX2)		0.05	0.02	<.01†‡	–1.42	0.65	0.03*

* = Statistically significant at the 0.05 level for INT mean

† = Statistically significant at the 0.05 level for INT variability as measured by log(SD)

‡ = Statistically significant at the 0.05 level for INT variability as measured by log(range)

SD = standard deviation, SE = standard error, A = angry, S = sad, H = happy, N = neutral,

TX1 = treatment 1, TX2 = treatment 2, LS = least squares

ry dependent variables. Overall, F0 variability and mean appeared to increase more with TX1 in comparison to TX2, while INT variability and mean appeared to be more influenced by TX2. These findings are especially interesting considering that previously reported data from perceptual analysis suggested a greater treatment effect for TX1 vs. TX2 for these three participants. This suggests that the perceptual judges of affective prosody may have been more influenced by changes in F0 than INT when assessing the emotional content of the speech productions. Considering the general consensus in the literature that F0, particularly its variation, has primacy in transmitting emotional prosody, these findings may not be unexpected. However, much more investigation will be required to further understand the effects of behavioral treatments for aprosodia, including the relationship between perceptual and acoustic findings.

Our secondary purpose was to determine whether the F0 and INT mean and variability were significantly different across the tested emotional tones of speech (i.e., happy, sad, angry, and neutral). With regards to F0 mean and variability, pairwise comparisons revealed differences in these measures across all emotions except for a lack of difference between neutral and sad speech in terms of variability. We also predicted significant, albeit less robust, differences would be present between emotional tones of speech with regards to INT mean and variation. However, differences in INT mean and variability across emotions were more robust than expected. All tested emotions were significantly different in terms of these values, except for a lack of difference in variability between happy and neutral speech and mean INT between angry and happy speech. Both of these findings appear consistent with the literature on affective prosody, although the latter may be a bit more intuitive.

These three participants all randomly received the treatments in the same order. That is, TX1 was the imitative treatment and TX2 was the cognitive-linguistic treatment (see Rosenbek et al., 2006 for more details). Current data do not allow for speculation of the relative value of one approach over another, but present and past data suggest both treatments were active in these three participants. Data from the larger sample of 14 participants reported that response to the first treatment was always greater than with the second treatment, regardless of which came first. The present data suggest that both TX1 and TX2 were active in these three participants in terms of both F0 and INT mean and variability. Additional investigation will be required to further determine the relative benefit on one approach over another.

As with all clinical studies with a degree of experimental control, this one requires cautious interpretation but provides some directions for programmatic research. Although 838 sentences were analyzed, only three participants were included. Clearly a larger sample of participants is critical, as is the computation of additional acoustic measures. Timing or durational measures will be of particular value in future work using acoustic analysis to determine treatment effect in patients with aprosodia. Further refinement of how clinicians are trained to deliver aprosodia treatment protocols is necessary and future studies may benefit from adding biofeedback to the treatment protocol. This could, for example, include using the biofeedback speech instrumentation Visi-pitch© to deliver information about F0 and INT variability. This may also prove beneficial for training clinicians, particularly during the use of an imitative treatment approach. Further analyses using these acoustic recordings also may be instructive in clarifying the effects of treatment. For example, perceptual ratings by blinded listeners using a more global measure of speech adequacy such as naturalness may help more clearly define response to treatment. Prosodic variation may as easily produce unnatural sounding speech as natural sounding. Therefore, judgments not only of difference but also of degree of difference and of approximation to normal emotional prosody may be profitably added to subsequent research paradigms. Additionally, the present study measured acquisition of these speech behaviors, as the posttest sessions were conducted immediately following completion of treatment. It may be prudent in future studies to measure retention or, more ambitiously, generalization of treatment effects.

Disorders of emotional prosody can have functional consequences. Their treatment is handicapped by a relatively small treatment literature and by the challenges of recruiting and retaining those right hemisphere damaged participants who most frequently have aprosodia. Expanding the treatment literature with refined treatment and analysis methods is one of our laboratory's programmatic goals. These data provide additional support that the previously described mechanism-based treatments (Leon et al., 2005; Rosenbek et al., 2004; Rosenbek et al., 2006) are active in the rehabilitation of aprosodia. Weismer (1984) and Kent et al. (1999) have recommended that acoustic analysis be used to measure treatment effects discretely and quantitatively. The results of this study with its accompanying acoustic data are a beginning toward such quantification.

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