Intonational Impairment Following Naturally Occurring Callosal Disconnection

Gayle V. Klouda, Donald A. Robin, Neill R.
Graff-Radford, and William E. Cooper

University of Iowa, Iowa City, Iowa

In recent years, a good deal of research has been devoted to determining the neurological substrates of speech prosody (e.g., Ross and Mesulam, 1979; Ryalls, 1982; Danly, Cooper and Shapiro, 1983; Cooper, Soares, Nicol, Michelow, and Goloskie, 1984; Shapiro and Danly, 1985). Prosody refers to variations in three acoustic properties of the speech wave (duration, amplitude, and fundamental frequency) which can alter the meaning of spoken language. The communicative functions of speech prosody include conveying emotional tone (e.g. Williams and Stevens, 1972; Cosmides, 1983; Scherer, 1986), as well as conveying linguistic distinctions, such as syntactic structure (e.g. Lea, 1973; Cooper and Sorensen, 1981) and stress assignment (e.g. Cooper, Eady, and Mueller, 1985). In this paper we are primarily concerned with the importance of interhemispheric connections to the processing of such prosodic features.

The left hemisphere is generally considered dominant for most language functions. Nevertheless, deficits in speech prosody have been observed for patients sustaining unilateral brain damage to either left or right cerebral hemispheres (e.g. Dordain, Degos and Dordain, 1971; Tucker, Watson and Heilman, 1977; Ross and Mesulam, 1979; Weintraub, Mesulam and Kramer, 1981; Monrad-Krohn, 1947; Danly, Cooper and Shapiro, 1983; Danly and Shapiro, 1982). Such findings indicate that the right hemisphere ordinarily contributes to the processing of prosodic information. However, studies of split-brain patients suggest that the disconnected right hemisphere does not as a rule possess the capacity for speech production (see Gazzaniga, 1983, for a review). Thus, it might be assumed that any prosodic information processed in the right hemisphere must in some way be transferred to the left hemisphere speech centers during speech production. Several researchers have suggested that this integrative function most likely occurs via the corpus callosum (e.g. Ross, Harney, deLacoste-Utamsing, and Purdy, 1981; Speedie, Coslett and Heilman, 1984). In fact, Watson and Heilman (1983) did note inability to repeat affective tone properly in a case of callosal disconnection. In addition, Speedie et al. (1984) studied prosody in two patients with mixed transcortical aphasia and found that, despite intact propositional speech, these patients were unable to repeat affective prosody. Since such aphasic patients typically sustain left hemisphere lesions that isolate but spare the perisylvian speech regions, the authors attributed the loss of affective tone to the loss of right hemisphere input to the speech centers.

While the above studies lend some support to the notion that callosal connections are important to the production of speech prosody, they both contain two important limitations. First, both studies relied on listening judgments to determine prosodic adequacy. The human ear, however, often is a poor judge of acoustic reality (e.g., Lieberman, 1965; Breckenridge, 1977). Also, since prosody refers to variations in three acoustic properties, without acoustic analysis it is not possible to determine which of these elements may have accounted for the perceived dysfunction.

Secondly, both studies reported deficits in affective prosody only. Apparently there is no information available regarding the importance of callosal connections to linguistic prosodic features. This is a particularly important issue since the loss of affective prosody only does not necessarily imply that callosal connections are directly involved in prosodic processing. Instead, such loss could occur as a secondary consequence of right hemisphere involvement in processing emotional characteristics (e.g., Tucker, Watson, and Heilman, 1977; Heilman, Scholes, and Watson, 1975; Wapner, Hamby, and Gardner, 1981), which in turn are known to influence speech prosody (e.g., Williams and Stevens, 1972; Cosmides, 1983). The hypothesis that callosal connections are directly involved in prosodic processing would be better supported by evidence of impairment to both affective and linguistic prosodic features following callosal disconnection.

Recently, we had the opportunity to examine prosody in a patient with a naturally occurring callosal lesion involving the anterior four-fifths of the corpus callosum, as documented in serial MRI scans. In order to examine the issues outlined above, we assessed the effects of her loss of interhemispheric connections on acoustic measures of Fo and duration, utilizing both emotional and nonemotional sentences.

Prosodic Evaluation. We tested the patient's prosody longitudinally at four weeks, four months, and one year after surgery. Two production tests were administered during each test period. The first test assessed the patient's ability to modulate prosody in order to signal emotional mood and the linguistic contrast between interrogative and declarative sentences. The subject was instructed to read four sentences (e.g., "Tomorrow I'm leaving for Chicago") with a happy, sad, angry, neutral, and questioning tone of voice. The second test assessed the patient's utilization of intonation to signal emphatic stress. For this test, the subject was asked to read six sentences (e.g., "Don shot the puck to Kent.") in response to each of three priming questions such as the following.

What happened?
Who shot the puck to Kent?
Who did Don shoot the puck to?

Such questions elicited neutral, sentence-initial, and sentence-final stress versions, respectively.

For both production tests, all items were presented randomly and the subject's utterances were tape-recorded. The recorded sentences were digitized at a sampling rate of 10 kHz on a PDP-11/23 computer, and a Fo contour for each digitized sentence was obtained using a time-domain pitch-detection algorithm (described in Cooper and Sorensen, 1981). In addition, durational analyses were performed with wide band (300 Hz) spectrograms.

RESULTS

Results of the fundamental frequency analyses are presented in Table 1 and Table 2. It can be seen from Table 1 that the patient exhibited little Fo distinction with intended mood at Time 1. However, her peak values did differ as a function of mood at Time 2 and Time 3, consistent with normative data for neurologically unimpaired subjects (Williams and Stevens, 1972; Cosmides, 1983; Scherer, 1986; Colsher, 1986). This improvement in speech production was accompanied by an improvement in perceptual judgments of her intended tone by six normal listeners. These data provide acoustic evidence of the loss of affective Fo distinctions immediately following callosal disconnection, with improvement as a function of time post-surgery.

Table 1. Mean fundamental frequency (Hz) averaged across the four sentences of Test 1 (values in parentheses are standard deviations).

Test Period	Sentence Type				
	Happy	Sad	Angry	Neutral	Question
Time 1	186 (15.3)	179 (12.4)	182 (16.9)	175 (14.5)	188 (24.6)
Time 2	248 (49.3)	217 (38.5)	244 (29.0)	187 (23.8)	217 (31.5)
Time 3	234 (58.2)	202 (25.8)	204 (33.2)	176 (18.9)	205 (33.4)

Table 2. Mean fundamental frequency (Hz) of key words averaged across the six sentences of Test 2 (values in parentheses are standard deviations).

Test Period	Stress Location	Key word position		
		1	2	3
Time 1	Initial	195 (12.2)	160 (8.5)	157 (10.4)
Time 1	Final	190 (14.7)	187 (6.3)	191 (9.2)
Time 1	Neutral	193 (5.5)	193 (6.7)	183 (20.9)
Time 2	Initial	205 (10.2)	163 (6.6)	144 (13.4)
Time 2	Final	205 (9.0)	191 (9.8)	191 (17.1)
Time 2	Neutral	196 (9.3)	180 (10.1)	175 (29.1)
Time 3	Initial	220 (21.3)	155 (16.0)	137 (21.2)
Time 3	Final	200 (10.5)	191 (6.4)	206 (21.0)
Time 3	Neutral	193 (4.1)	183 (10.1)	187 (23.3)

While our patient exhibited little affective Fo distinction at Time 1, she did exhibit a characteristic Fo rise preceding the final words of question forms. In addition, as previously noted for normal speakers (e.g., Eady and Cooper, 1986), this terminal rise resulted in considerably higher final Fo values for questions than for statements at all test periods. However, the difference between these final values was somewhat smaller at Time 1 (61 Hz) than at Time 2 (87 Hz) or Time 3 (82 Hz). Therefore, while the patient clearly maintained a Fo distinction between questions and statements following callosal damage, this distinction appears to have been somewhat diminished initially.

The patient's utterances also exhibited the influence of emphatic stress on Fo at the first test period, and again this distinction improved at each consecutive test period. For example, normal speakers generally produce a precipitous drop in Fo immediately following an initial stressed word (Eady, Cooper, Klouda, Mueller, and Lotts, 1986). As can be seen from Table 2, our patient also exhibited a drop in Fo between the first and second keywords at Time 1 (32 Hz). However, this drop more than doubled by Time 3 (65 Hz).

Results of the durational analyses indicated appropriate emotive and nonemotive suprasegmental distinctions on most sentences. For example, consistent with normal data (Williams and Stevens, 1972; Eady _et al._, 1986; Eady and Cooper, 1986), she consistently elongated sad sentences, sentence-final words in question forms, and words receiving contrastive stress. However, while these suprasegmental durational features were intact, segmental analyses revealed abnormal VOTs and increased second formant frequency durations at Time 1, which resolved by Time 2.

CONCLUSIONS

The present results provide the first acoustic evidence that speech prosody is impaired following callosal damage. Impairment was evident for affective and linguistic Fo distinctions, while durational measures appeared to be relatively intact at four weeks post-surgery. These results closely parallel recent findings of affective and linguistic Fo deficits following right brain damage (e.g., Shapiro and Danly, 1985; Colsher _et al._, 1987). Together, such findings provide strong evidence that the right hemisphere generally contributes to the processing of Fo information. Moreover, the present results suggest that this input is communicated to the left hemisphere speech centers via the corpus callosum.

In the introduction, we stated that prosodic deficits specific to affective speech could be produced as a secondary consequence of the right hemisphere's association with emotional characteristics. While our results do suggest that the effects of callosal damage were particularly strong for emotionally laden sentences, deficits were observed in nonemotive sentences as well. Furthermore, as indicated above, linguistic prosodic deficits have also been observed in patients sustaining right hemisphere damage. Taken together, these results indicate that right hemisphere involvement in prosodic programming cannot be characterized exclusively in terms of the processing of emotional information. Instead, the right hemisphere appears to be directly involved in processing Fo information which is then transferred to the left hemisphere via the corpus callosum.

It should be noted that, while depression can influence prosody (e.g., Hargreaves, Starkweather, and Blacker, 1965; Roessler and Lecter, 1976;

Swanson, 1977), it is unlikely that depression was a major factor in our patient's performance. First, when her prosody was worst (at 4 weeks post surgery) she was noted not to be depressed. Second, when she did report some symptoms of depression (at 4 months), her performance in the tests had improved.

The fact that durational measures were relatively intact in this patient suggests that, unlike Fo, duration may be processed primarily in the left hemisphere. This conclusion is consistent with the results of several studies of speech perception in normal and brain-damaged subjects. For example, although the results of dichotic listening studies in normals have not been entirely consistent, they have generally indicated a right ear dominance for temporal information and a left ear dominance for pitch perception (Blumstein and Cooper, 1974; Berlin and McNeil, 1976; Gregory, 1982; Sidtis, 1984). Additionally, Dvenyi and Robinson (1986) reported that brain-damaged patients with left hemisphere lesions were most impaired on temporal perception tasks while right hemisphere patients were most impaired on frequency tasks. Also, Robin et al. (1987) found impaired pitch perception but no impairment in temporal perception for two right-hemisphere-damaged patients.

Finally, although our patient exhibited Fo deficits initially, she showed considerable improvement with respect to both affective and linguistic Fo distinctions as a function of time post-surgery. Furthermore, these improvements in speech production were accompanied by improvements in the perceptual judgment of her intended tone by normal listeners. Such improvement may imply that, while the right hemisphere generally contributes to Fo programming, after callosal damage, such programming can be performed by the left hemisphere. This hypothesis is supported by evidence that some right-brain-damaged patients also exhibit more normal Fo patterns when tested at six months rather than immediately post-stroke (Colsher et al., 1987).

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