28. Auditory Processing of Sequential Pitch and Timing Changes Following Frontal Opercular Damage

Karen A. Colson, Donald A. Robin, and Erich S. Luschei

Much research has been undertaken to examine normal and brain-injured subjects' auditory processing of spectral and temporal information in linguistic (Basso, Cosati, & Vignolo, 1977; Blumstein, Cooper, Zurif, & Caramazza, 1977; Carpenter & Rutherford, 1973; Emmorey, 1987; Leeper, Shewan, & Booth, 1986) and nonlinguistic contexts (Divenyi & Robinson, 1989; Divenyi & Signoret, 1988; Efron, 1963; Marchman, 1969; Mills & Rollman, 1979; Needham & Black, 1970; Robin, Eslinger, Tyler, & Damasio, 1987; Robin, Tranel, & Damasio, 1987; Van Allen, Benton, & Gordon, 1966). Evidence suggests that neural regulation of auditory perception processes involves different cortical areas in both cerebral hemispheres. Findings also indicate that hemispheric mediation of acoustic signals may differ according to processing requirements that involve spectral and temporal parameters. In this regard, researchers (Divenyi & Signoret, 1988; Hammond, 1982; Mills & Rollman, 1979; Robin, Tranel, & Damasio, 1987; Tallal & Newcombe, 1978) have suggested that an intact left cerebral hemisphere is crucial to the accurate analysis of temporal information, especially of rapidly changing acoustic events. In contrast, cortical mediation of spectral processing typically has been attributed to the right hemisphere (Divenyi & Robinson, 1989; Divenyi & Signoret, 1988; Robin, Tranel, & Damasio, 1987). Hence, both hemispheres may be involved in

The authors wish to thank Dr. Neil Graff-Radford for his assistance in locating the subjects for this study. A special note of thanks is due to Dr. Hanna Damasio for providing the lesion localization data.

This research was supported in part by NIH Grant PON19632, on which the second author is an investigator.

the processing of linguistic and nonlinguistic signals. However, the mediation of temporal processing by the left hemisphere may be particularly vital to the maintenance of speech and language functions (Efron, 1963; Hammond, 1982; Mills & Rollman, 1979; Robin, Tranel, & Damasio, 1987).

Currently, the relationship between focal, unilateral cortical insult and deficits in spectral and temporal processing remains unclear. Psychoacoustic study of spectral and temporal processing in the same patient population has been limited. Further, it has yet to be determined if focal, unilateral, anterior cerebral insult may be associated with differential deficits in processing nonlinguistic spectral and temporal information. These issues are critical to an understanding of the neural regulation of basic auditory perceptual processes. Moreover, because these basic decoding levels may be associated with higher-level linguistic functions, more thorough analysis of anterior lesion patients' spectral and temporal processing appears warranted.

The present study examined selected spectral and temporal processing abilities of patients with well-defined lesions of the left frontal opercular region. Specifically, this study sought to determine if these patients differ from normal adults in their ability to identify changes in the pitch and/or duration of sequenced tones.

METHODS

Subjects

The subjects were five normal adults, five left-hemisphere-damaged patients, and two right-hemisphere-damaged patients (Table 28.1.). All were native English speakers and had hearing sensitivity thresholds of at least 30 dB hearing level (HL) in the better ear. The normal group and the left-hemisphere group were matched for age and sex.

Patient selection was based primarily on neuroanatomical data obtained from a standard computerized tomography and/or magnetic resonance imaging scan localization protocol (Damasio, 1983, 1987). Each patient had a medically diagnosed history of a single, focal left- or right-hemisphere lesion in any or part of the areas defined as the precentral cortex, premotor cortex, Broca's area and surrounding structures (e.g., Brodmann's area 44 and 45), and insular cortex. Localization data for each left anterior lesion (LAL) and right anterior lesion (RAL) patient are provided in Figure 28.1. Sample size was limited by the availability of patients who met the rigid localization criteria. Other criteria excluded patients whose

TABLE 28.1. SUBJECT INFORMATION

Subject	*Age*	*Sex*	*Etiology*	*Years Post-Onset*
Left				
LAL1	44	M	Thrombotic	3.9
LAL2	50	M	Embolic	2.3
LAL3	68	F	Thrombotic	1.7
LAL4	67	M	Thrombotic	4.2
LAL5	64	M	Thrombotic	1.0
Right				
RAL1	64	M	Thrombotic	1.2
RAL2	34	M	Embolic	2.0
Normal				
N1	44	M		
N2	50	M		
N3	69	F		
N4	68	M		
N5	63	M		

medical records indicated a history of seizures, signs of dementia or psychosis, or major health complications. Speech-language testing (Goodglass & Kaplan, 1983; Schuell, 1973) indicated that all patients were able to respond appropriately and reliably to verbal input (e.g., questions and commands), recall three-part verbal sequences, and orally read printed materials (e.g., digits, simple words). In addition, all patients demonstrated the ability to discriminate between high- and low-sounding tones and between long and short tonal lengths.

Procedures

Three separate experiments were conducted to examine each subject's perception of changes in pitch, duration, and a combination of pitch and duration. Stimuli were generated by an IBM PC/AT computer and consisted of three successive square-wave tone bursts separated by a 100-ms intertone interval. In each experiment, the tonal sequences were generated randomly in one of four patterns, so that either there was a difference in the fundamental frequency and/or duration of one tone, or all three tones were exactly the same. The schematic configurations in Figure 28.2 illustrate the four tonal patterns used as stimuli in the combined pitch and duration perception task. In all experimental conditions, the standard tones in patterns 1–3 were always 250 Hz and 100 ms. All frequency and timing operations were controlled by the computer.

Subject	*Lesion Locus*
LAL1	Left frontal lobe: most superior tip of frontal operculum and premotor region immediately above (cortices and underlying white matter)
LAL2	Left frontal lobe: posterior part of frontal operculum and premotor and motor region immediately behind, anterior portion of insula (cortices and underlying white matter)
LAL3	Left frontal lobe: the frontal operculum and premotor and motor region immediately behind and superiorally, anterior part of insula (cortices and underlying white matter)
LAL4	Left frontal lobe: frontal operculum and premotor region immediately above, extends deep into white matter almost to frontal horn of lateral ventricle, involves insular cortex and white matter
LAL5	Left frontal lobe: premotor cortex and white matter just behind frontal operculum, extends deep in white matter to frontal horn of lateral ventricle and part of anterior limb of internal capsule, involves insular cortex and white matter and most of lenticular nucleus
RAL1	Right frontal lobe: small infarct involving cortex and subcortical white matter in lower portion of premotor area just behind frontal operculum
RAL2	Right frontal lobe: frontal operculum, extends deep into white matter to frontal horn of lateral ventricle, involves insular cortex and white matter and part of lenticular nucleus.

Figure 28.1. Lesion localization data for each brain-injured subject.

The test paradigm involved the use of adaptive procedures for the method of limits designed by Levitt (1971). Testing involved a series of trials in which systematic step changes in the frequency and/or duration of the comparison tones were made according to a 3-down, 1-up rule for maintaining approximately 78% response accuracy. Threshold testing was begun immediately after a series of practice trials, at the point (e.g., comparison tone difference value) where the last accurate response was given. Using a four-alternative, forced-choice method of response, the subject identified whether or not any tone in a stimulus sequence was higher in pitch and/or longer than the other tones. Four series of turn-arounds (ascending and descending) with a 20% step size change in frequency and/or duration were completed by each subject. The stimuli were presented through headphones to the subject, who was seated in a sound-treated booth. Responses were stored in a file by the computer.

Each LAL subject performed the three experiments in a different order. Matched brain-injured and control subjects were tested in the same order. RAL1 performed the tasks in a different order from RAL2.

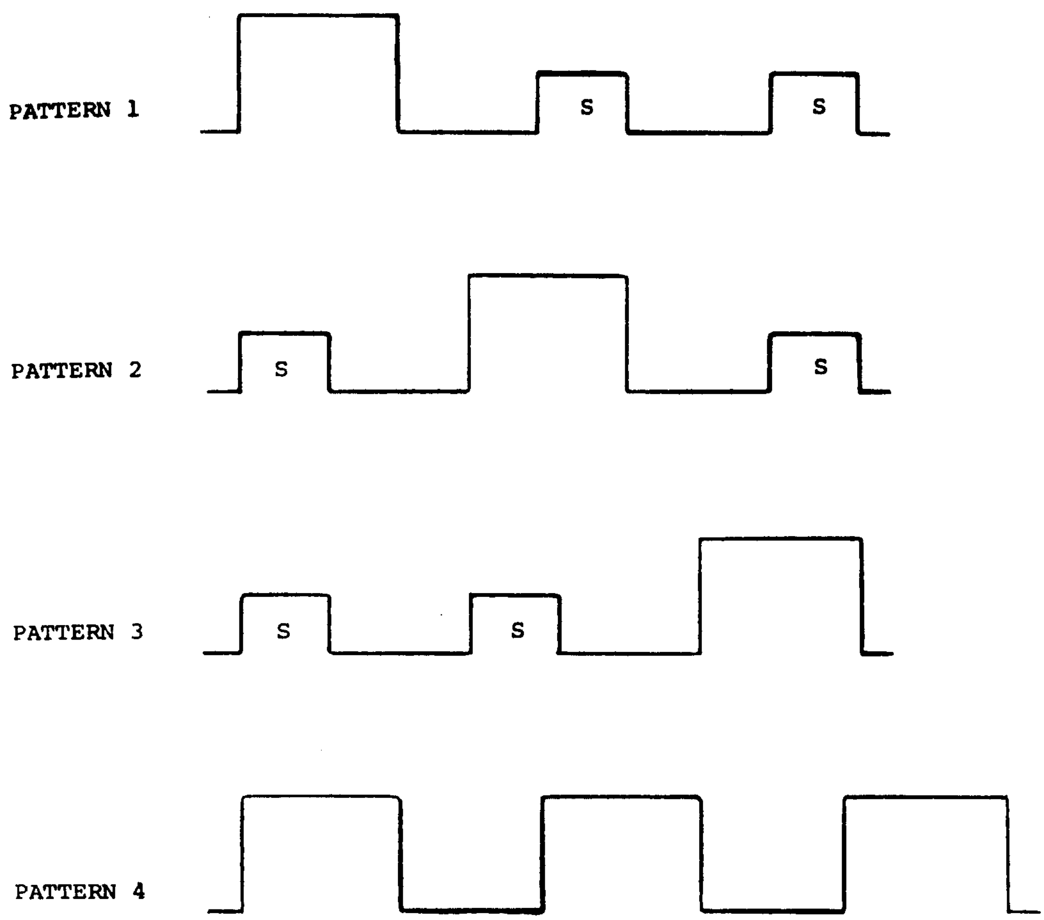

Figure 28.2. Schematic configurations illustrating the four tonal patterns used as stimuli in the combined pitch and duration perception task. Each square symbolizes a component tone in the three tone sequences. Standard tones are indicated by the letter "S." Changes in the fundamental frequency and duration of comparison tones are indicated by increased size in the squares representing the tones.

The data were analyzed to determine each subject's average threshold per condition. For statistical purposes, an average difference value also was determined for each subject per condition. The average difference was defined as the numerical difference in hertz and/or milliseconds between a subject's average threshold and the standard tone value for each task.

RESULTS

Table 28.2 shows the average difference between the tones that was necessary for the LAL and normal groups to accurately identify relative changes in pitch and/or duration. The LAL group typically had a higher average threshold and greater performance variability than the controls. The LAL subjects' marked variability in performing the duration task precluded evaluation of the groups' means with a multivariate analysis of variance. Therefore, the groups' perceptual measures for each task were compared using a Mann-Whitney *U* test (Kirk, 1982). As shown in Table 28.3, in comparison to the normal subjects, the LAL group typically required a significantly larger difference between the standard and comparison tones to accurately identify relative changes in pitch and/or duration.

The average standard and comparison tone difference at which the subjects with right anterior lesions accurately identified pitch and/or duration changes is shown in Table 28.4, along with data for the LAL and normal groups. Comparison of the RAL patients' respective data indicates that all of RAL1's means are lower than those of RAL2. Nevertheless, both RAL patients' means were similar in value to those of the normal group and considerably lower than those of the LAL group. Moreover, these findings indicate that each RAL patient tended to have a lower average threshold than the LAL subjects for identifying relative pitch and/or duration changes in the tonal sequences.

DISCUSSION

From the results it may be inferred that there is no common association between focal, unilateral cortical insult and impaired perception of relative changes in sequenced, nonlinguistic pitch and duration properties. The findings suggest that the LAL group's perception deficits were not a general result of cerebral injury, but rather were caused by selective impairments associated with focal, left-anterior damage.

In speculating as to the functional relationship between the LAL group's impaired pitch and duration perception, it may be important to consider the temporal processing requirements of the tasks. Each task required that the subjects judge whether a relative change in pitch and/or duration occurred and, if so, identify the temporal order of the change in the acoustic sequence.

In responding, the LAL subjects often inaccurately identified sequences with a pitch and/or duration change as being neutral and as having no variations. This type of identification error suggests difficulty in perceiving the actual occurrence of change, rather than an inability to make judgments of temporal order. Perhaps the LAL patients' perceptual processing deficits were related to the rapid temporal onset of changes in the tonal stimuli. In particular, the 100-ms intertone interval within each

TABLE 28.2. LAL AND NORMAL GROUPS' PITCH AND DURATION PERCEPTION DATA

	Average Difference		
Subjects	PITCH (HZ)	DURATION (MS)	PITCH AND DURATION (HZ AND MS)
LAL			
Mean	228.40	1,548.20	154.80
SD	31.59	1,562.77	82.48
Normal			
Mean	12.80	122.20	30.20
SD	6.83	48.16	39.98

TABLE 28.3. RESULTS OF MANN-WHITNEY *U* TEST COMPARING LAL AND NORMAL GROUPS' PERCEPTUAL MEASURES FOR PITCH AND/OR DURATION EXPERIMENTS

Perceptual Task	U *Statistic*	p
Pitch changes	0	.004
Duration changes	1	.008
Pitch and duration changes	2	.016

TABLE 28.4. RAL PATIENTS' AND LAL AND NORMAL GROUPS' PITCH AND DURATION PERCEPTION DATA

	Average Difference		
Subjects	PITCH (HZ)	DURATION (MS)	PITCH AND DURATION (HZ AND MS)
RAL1			
Mean	6.76	102.90	8.83
SD	2.01	45.92	2.04
RAL2			
Mean	87.23	204.42	73.37
SD	28.22	17.62	19.97
LAL Group			
Mean	228.40	1,548.20	154.80
SD	31.59	1,562.77	82.48
Normal Group			
Mean	12.80	122.20	30.20
SD	6.83	48.16	39.98

sequence and the 100-ms standard tone duration in each task may have been too brief to allow the LAL subjects to adequately perceive the occurrence of a pitch and/or duration change in the comparison tone. It is possible, therefore, that in decoding the changes in the tonal sequences, a complex interaction took place between spectral and temporal features that resulted in processing difficulties for the LAL subjects. This view is concordant with prior findings that the overall temporal structure of tonal sequences may influence normal and left-hemisphere-impaired subjects' decoding of spectral and temporal changes (Divenyi & Robinson, 1989; Divenyi & Signoret, 1988; Hammond, 1982; Mills & Rollman, 1979; Robin, Tranel, & Damasio, 1987). Further, the present findings provide support for the view that some lower-level auditory processing disturbances may be associated with focal, left-anterior damage and, hence, higher-level linguistic impairments (Efron, 1963; Leeper et al., 1986; Robin, Tranel, & Damasio, 1987; Tallal & Newcombe, 1978).

REFERENCES

Basso, A., Cosati, C., & Vignolo, L. (1977). Phonemic identification defects in aphasia. *Cortex, 13,* 84–95.

Blumstein, S., Cooper, W., Zurif, E., & Caramazza, A. (1977). The perception and production of voice-onset time in aphasia. *Neuropsychologia, 15,* 371–383.

Carpenter, R., & Rutherford, D. (1973). Acoustic cue discrimination in adult aphasia. *Journal of Speech and Hearing Research, 16,* 534–544.

Damasio, H. (1983). A computer tomographic guide to the identification of cerebral vascular territories. *Archives of Neurology, 40,* 138–142.

Damasio, H. (1987). Vascular territories defined by computed tomography. In J. Wood (Ed.), *Cerebral blood flow: Physiologic and clinical aspects* (pp. 239–250). New York: McGraw-Hill.

Divenyi, P., & Robinson, A. (1989). Nonlinguistic auditory capabilities in aphasia. *Brain and Language, 37,* 290–326.

Divenyi, P., & Signoret, J. (1988). *Auditory performance and central nervous system damage.* Unpublished paper.

Efron, R. (1963). Temporal perception, aphasia and *déjà vu. Brain, 86,* 403–424.

Emmorey, K. (1987). The neurological substrates for prosodic aspects of speech. *Brain and Language, 30,* 305–320.

Goodglass, H., & Kaplan, E. (1983). *The assessment of aphasia and related disorders* (2nd ed.). Philadelphia: Lea & Febiger.

Hammond, G. (1982). Hemispheric differences in temporal resolution. *Brain and Cognition, 1,* 95–118.

Kirk, R. (1982). *Experimental design: Procedures for the behavioral sciences* (2nd ed.). Monterey, CA: Brooks Cole.

Leeper, H., Shewan, C., & Booth, J. (1986). Altered acoustic cue discrimination in Broca's and conduction aphasics. *Journal of Communication Disorders, 19,* 83–103.

Levitt, H. (1971). Transformed up-down methods in psychoacoustics. *Journal of Communication Disorders, 19,* 83–103.

Marchman, J. (1969). Discrimination of brief temporal durations. *Psychological Record, 19,* 83–92.

Mills, L., & Rollman, G. (1979). Left hemisphere selectivity for processing duration in normals. *Brain and Language, 7,* 320–335.

Needham, E., & Black, J. (1970). The relative ability of aphasic persons to judge the duration and intensity of pure tones. *Journal of Speech and Hearing Research, 13,* 725–730.

Robin, D., Eslinger, P., Tyler, R., & Damasio, H. (1987). *Impaired pitch perception following focal right hemisphere damage.* Paper presented at the 39th meeting of the Academy of Neurology, New York, NY.

Robin, D., Tranel, D., & Damasio, H. (1987). *Deficits in temporal and spectral perception following focal cerebral damage.* Paper presented at the Academy of Aphasia, Phoenix, AZ.

Schuell, H. (1973). *Minnesota Test for Differential Diagnosis of Aphasia* (rev. ed.). Minneapolis, MN: University of Minnesota Press.

Tallal, P., & Newcombe, F. (1978). Impairment of auditory perception and language comprehension in dysphasia. *Brain and Language, 5,* 13–24.

Van Allen, M., Benton, A., & Gordon, M. (1966). Temporal discrimination in brain-damaged patients. *Neuropsychologia, 4,* 159–167.