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CORTICAL REPRESENTATION OF SPEECH PERCEPTION AND PRODUCTION, AS REVEALED BY DIRECT CORTICAL ELECTRICAL INTERFERENCE

Dana F. Boatman[1,2,4], *Ronald P. Lesser*[1,3,4], *and Barry Gordon*[1,2,4]

Departments of Neurology[1], Cognitive Science[2], and Neurosurgery[3], and the Zanvyl Krieger Mind/Brain Institute[4], Johns Hopkins University, Baltimore, MD, USA

ABSTRACT

The relationship between speech perception and production was studied using deficits produced by direct cortical electrical stimulation. Stimulation was applied through indwelling subdural electrode grids in three patients with epilepsy. Without stimulation, patients performed at ceiling on tasks of auditory syllable discrimination, identification, comprehension, naming, reading, and repetition. With electrical interference, speech perception and production errors co-occurred at multiple sites on the lateral left temporal and inferior frontal cortex. These findings add to existing evidence that suggest that some aspects of speech perception and production share functional and neural resources. This in turn argues against classical notions of a strict functional and anatomic separation between speech perception and speech production.

INTRODUCTION

Speech perception and production have traditionally been represented as distinct functional and neural systems. Early studies of patients with focal brain injuries and accompanying language impairments provided evidence supporting the distinctness of these two language functions. Post-mortem studies of patients with speech production impairments reported lesions involving a relatively circumscribed region of the left inferior frontal lobe, also known as Broca's area. Conversely, patients with impaired auditory comprehension were reported to have lesions located more posteriorly in the left posterior temporal, or Wernicke's area. In keeping with the non-convergent view, patients presenting with concomitant speech perception and production deficits, or global aphasia, were reported to have large lesions involving both speech areas.

Although the neurofunctional separation of speech perception and production is still widely accepted, the advent of sophisticated brain imaging techniques has yielded conflicting evidence. Detailed CT studies of patients presenting with speech production deficits have revealed lesions extending well beyond the left frontal operculum [4]. It has also been observed that concomitant speech perception and production deficits can result from lesions involving either of the two classical speech areas [1,8]. These studies suggest that the neural mechanisms of speech perception and production are more diffusely represented than was previously postulated, and that they may also share certain neurofunctional resources.

Despite recent evidence of neural, and by extension functional, overlap of speech perception and production, a number of potentially confounding issues associated with studies of aphasic patients have impeded any definitive conclusions. One issue is that lesions associated with language impairments tend to be relatively large [5], potentially involving multiple functionally-specific cortical regions. Consequently, involvement of multiple cortical regions may generate the impression of functional convergence. A second potentially confounding issue is that aphasic patients are generally studied post-acute onset when cortical reorganization may have been implemented. Accordingly, data from lesion studies may reflect the cortical reorganization of two functions to the same region. Another concern is the frequent use of group comparisons to provide information on multiple lesion sites, but which are potentially confounded by individual patient and methodological differences. Finally, early aphasia studies generally assessed only one measure of speech perception, namely auditory comprehension. Subsequent research, however, has indicated that speech perceptual functions may differ greatly in their neurofunctional requirements [2]. Accordingly, multiple speech perceptual functions would need to be assessed in order to obtain a comprehensive view of the neurofunctional relationship between speech perception and production.

To obtain a more comprehensive understanding of the neurofunctional relationship between speech perception and production, we studied the acute effects of direct cortical electrical interference on multiple speech perception and production functions that were tested at different sites in the same patients, with indwelling subdural electrode arrays.

METHODS

Patients. Three patients, two males (ages 17 and 23) and one female (age 37) presented as surgical candidates for treatment of intractable epilepsy. Clinical testing revealed no hearing, speech, language, verbal memory, or other cognitive impairments. All 3 patients obtained full-scale IQ scores above 85, and left-hemisphere dominance for language was confirmed by intracarotid amobarbital injection. As part of the evaluation for left temporal resection treatment, patients had placement of an indwelling subdural electrode grid of 2 mm (exposed) electrodes with 10 mm inter-electrode separation. The array covered the left lateral inferior frontal, parietal, and temporal regions. Electrode locations were determined by normalizing their positions within a standard brain atlas [6]. Electrical interference testing was performed according to preestablished protocols [3]. Testing at adjacent electrodes included motor and sensory assessment, as well as the evaluation of general language functions. Specific electrode pairs in the inferior frontal and posterior temporal region were associated with speech perception and production errors. These were investigated further.

Experimental testing, with and without electrical stimulation, was performed to investigate the relationship between the perception and production of consonant-vowel-consonant (CVC) natural speech syllables. A set of 60 digitized CVC syllables were used to generate the following tasks:

A syllable discrimination task comprised 85 syllabic pairs that patients judged as Same or Different. Sixty pairs were contrasted in syllable-initial or syllable-final position by a stop consonant (/p,t,k,b,d,g/), or in syllable-medial position by one of five vowels (/i,e,a,o,u/). Twenty-five pairs were identical.

A syllable identification task involved 30 CVC items presented individually in a forced-choice, four alternative orthographic response format.

A syllable repetition task consisted of 30 CVC stimuli.

A picture naming task consisted of 30 imageable CVC stimuli that were presented visually on a computer monitor.

An oral word reading task comprised 30 CVC stimuli that were presented visually on a computer monitor.

To ensure comparability of patients' performance across tasks, a subset of the same 6 CVC stimuli were included on all tasks.

A phrasal comprehension task comprised 15 single-step auditory commands selected from the Token Test [7]. These were read aloud by a trained clinical technician whose face was not visible to the patients in order to avoid providing visual articulatory cues.

RESULTS

At baseline, all three patients performed at ceiling on tests of speech perception and production. Under electrical interference, patients' speech perception and production performances decreased significantly from their baseline performance levels at certain electrode sites located on the lateral surface of the posterior temporal and inferior frontal lobes (in all cases, $p < .02$; McNemar Exact tests).

Although speech perception errors occurred in both the frontal and temporal regions (see Fig. 1), more electrode sites in the posterior temporal region were associated with auditory comprehension errors than in the frontal regions of all three patients. This was not the case, however, for auditory syllable discrimination, which was associated with the same number of sites in both regions.

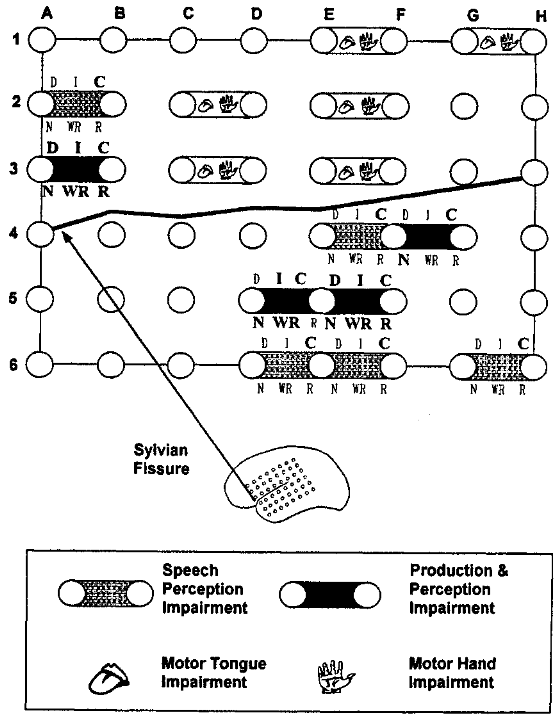

Fig. 1. Speech deficits elicited under electrical interference in one patient with indwelling subdural electrode array. Deficits are boldfaced. D=auditory syllable discrimination; I=auditory syllable identification; C=auditory comprehension; N=naming; WR=word reading; and R=repetition.

Speech production deficits occurred at sites in both the inferior frontal and posterior temporal regions of all three patients. Production errors elicited in the frontal region occurred at sites immediately adjacent to the motor area (hand and tongue).

Speech perception and production errors co-occurred at specific sites within both the posterior temporal and inferior frontal lobes. At one posterior temporal site in each patient, patients' performance on the syllable discrimination, syllable identification, auditory comprehension, and all three production tasks were impaired. In two of the three patients, the same pattern of deficits was also observed at one inferior frontal site. At other temporal and frontal sites, syllable identification and auditory comprehension were impaired as well as reading and naming, but syllable discrimination and repetition remained intact. At yet other temporo-frontal sites, auditory comprehension and naming were each selectively impaired.

DISCUSSION

Direct cortical electrical interference was applied through indwelling subdural electrode arrays covering the lateral cerebral cortex to investigate the relationship between speech perception and production. Under electrical interference, speech perception errors occurred in both posterior (temporal) and anterior (frontal) cortical regions. This suggests that neural resources other than the classical Wernicke's area are crucial for auditory speech processing. Although auditory comprehension deficits occurred more frequently in the posterior temporal lobe than in the inferior frontal region, this pattern of deficits was not observed for auditory syllable discrimination. Clinical evaluations of aphasic patients generally include only measures of auditory comprehension, thereby potentially accounting for the traditional view that speech perception is localized to posterior cortical regions.

Speech production deficits were also localized to both the inferior frontal and posterior temporal regions, again challenging the classical Broca-Wernicke neurofunctional distinction. Production deficits in the frontal region occurred at sites immediately adjacent to the motor area (hand and tongue) in all three patients. Because the effects of electrical interference were relatively circumscribed, it was possible to dissociate motor from speech responses. In patients with naturally-occurring lesions, however, such dissociations may not occur, generating the impression that speech production is more dependent on anterior cortical resources than on posterior cortical areas.

Concomitant speech perception and production errors were observed at specific sites in both cortical regions of our patients. The co-occurrence of perceptual and production errors at specific temporal as well as frontal sites disputes the traditional view that speech perception and production are subserved by distinct cortical regions. Our data suggest, instead, that speech perception and production share certain neural, and perhaps also functional, resources. Patients' high level of performance accuracy without electrical interference ensured closer approximation to the normal speech processing system than has previously been possible in lesion studies.

REFERENCES

[1] Basso, A., Lecours, A., Moraschini, S., & Vanier, M. 1985. Anatomo-clinical correlations of the aphasias as defined through computerized tomography: exceptions. *Brain and Language*, **26**, 201-229.

[2] Boatman, D., Lesser, R., and Gordon, B. Auditory speech processing in the left temporal lobe: an electrical interference study. In press.

[3] Lesser, R., Luders, H., Klem, G., Dinner, D., Morris, H., Hahn, J., & Wyllie, E. 1987. Extraoperative cortical functional localization in patients with epilepsy. *Journal of Clinical Neuropsychology*, **4**, 27-53.

[4] Mohr, J., Pessin, M., Finkelstein, S., Funkenstein, H., Duncan, G., and Davis, K. 1978. Broca aphasia: pathologic and clinical. *Neurology*, **28**, 311-324.

[5] Selnes, O., Niccum, N., Knopman, D., & Rubens, A. 1984. Recovery of single word comprehension: CT -scan correlates. *Brain and Language*, 21, 72-84.

[6] Talairach, J., & Tournoux, P. 1988. *Co-planar Stereotaxic Atlas of the Human Brain: 3-dimensional Proportional System: An Approach to Cerebral Imaging*. Stuttgart: Thieme.

[7] Vignolo, L. 1969. Auditory agnosia: A review and report of recent evidence. In A. Benton (Ed) *Contributions to Clinical Neuropsychology*. Chicago: Aldine.

[8] Willmes, K., & Poek, K. 1993. To what extent can aphasia syndromes be localized? *Brain*, **116**, 1527-1540.

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