

A new brain region for coordinating speech articulation

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HUMAN speech requires complex planning and coordination of mouth and tongue movements. Certain types of brain injury can lead to a condition known as apraxia of speech, in which patients are impaired in their ability to coordinate speech movements but their ability to perceive speech sounds, including their own errors, is unaffected¹⁻³. The brain regions involved in coordinating speech, however, remain largely unknown. In this study, brain lesions of 25 stroke patients with a disorder in the motor planning of articulatory movements were compared with lesions of 19 patients without such deficits. A robust double dissociation was found between these two groups. All patients with articulatory planning deficits had lesions that included a discrete region of the left precentral gyrus of the insula, a cortical area beneath the frontal and temporal lobes. This area was completely spared in all patients without these articulation deficits. Thus this area seems to be specialized for the motor planning of speech.

Stroke, head trauma, tumour or other neurological diseases can disrupt the articulation process. One such disruption, apraxia of speech, is a disorder in programming the speech musculature to produce the correct sounds of words in the proper sequence with the appropriate timing. Patients with this deficit make inconsistent articulatory errors approximating the target word, show articulatory groping, and often have an associated disruption in prosody and rate of speech (Box 1). Some consider apraxia of speech to be a disorder in temporal coordination in which 'the timing or integration of movements of two independent articulators' is affected (ref. 1, page 162). The disorder is not considered a

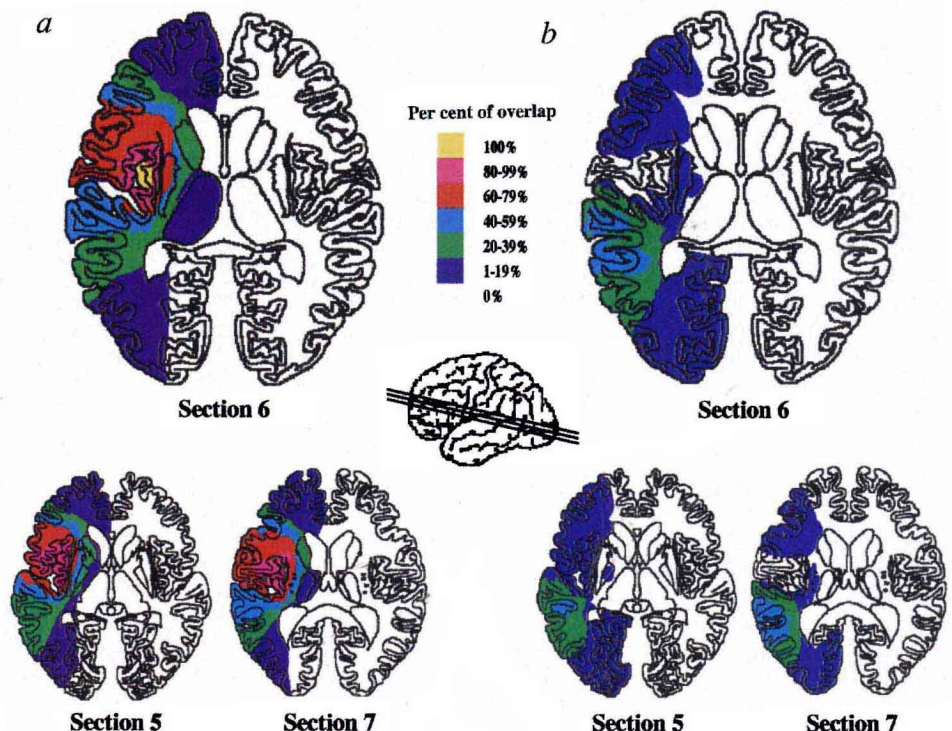
perceptual problem, as patients with apraxia of speech exhibit articulatory deficits in the absence of any difficulty in perceiving or recognizing speech sounds, including their own articulatory errors^{2,3}.

Computer reconstructions and overlapping of focal brain lesions derived from computerized axial tomography (CT) and magnetic resonance imaging (MRI) can help identify common areas of infarction in stroke patients with this and other disorders. In this study, lesions derived from CT and MRI scans of 25 patients with apraxia of speech were reconstructed onto templates and entered into a minicomputer using software and techniques developed at the VA Medical Center in Martinez, California⁴. Lesion overlays were produced by computer-superimposing lesions represented on each horizontal slice for all patients demonstrating the same articulatory deficit. In this manner, the extent to which all patients with apraxia of speech share a common lesion site could be determined.

One common area of infarction was found in all 25 cases. Figure 1a (top) depicts the lesion overlay for section 6 of the reconstruction program, containing the only region in which every patient had sustained injury. This area of 100% lesion overlap is shown in yellow and signifies the involvement of that region in each patient. It does not include any traditionally known language area, but lies within the insula, an island of cortex within the cerebral hemispheres. This common area of injury does not involve the entire insula but is confined to one discrete site and suggests the specialization of this area for the planning of articulatory movements. Although the association of a lesion site with a behavioural deficit is not conclusive proof that the site actually carries out that function, the strength of this particular association is difficult to ignore. Neighbouring sections 5 and 7 (Fig. 1a, bottom) also depict portions of the insula with 80-99% lesion overlap, but do not show a discrete area of infarction common to all patients as in section 6.

Given the significance of this finding, a means of corroborating these results was sought. A second group of 19 patients was selected who met similar selection criteria to the previous group. However, in this second group of patients similarly evaluated, none suffered from apraxia of speech. Lesion reconstructions in this group of patients were also overlapped to determine

FIG. 1 Comparison of computerized lesion overlapping in patients with and without apraxia of speech. *a*, Overlapping the lesions of 25 patients with apraxia of speech yields a common area of infarction (bright yellow) on section 6 of the reconstruction programme (top of the figure). This region represents an area of 100% overlap, that is, all 25 patients with this articulatory planning disorder have lesions that include this one area of the insula. In the bottom row are shown neighbouring sections either below (section 5) or above (section 7) the critical slice. *b*, Overlapping the lesions of 19 patients without apraxia of speech shows infarctions over much of the left hemisphere as in the previous group. However, a comparison of section 6 in the two groups reveals that not one of these 19 patients without apraxia of speech has a lesion in the same region of the insula as those who do exhibit the disorder. (The additional sparing of neighbouring motor face cortex is due to patterns of vascularization and stroke in this region.)



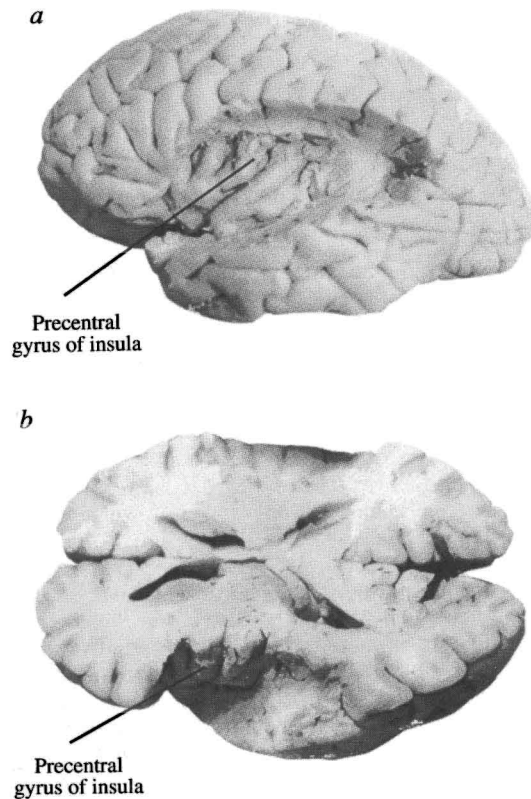


FIG. 2 Dissecting the brain at the same angle as the reconstruction templates revealed the location of the critical area for articulatory planning on the precentral gyrus of the insula. *a*, The insula lies exposed after cutting away the inferior frontal and parietal lobes and the anterior superior temporal lobe which collectively hide the insula. With this area now visible, the central insular (longitudinal) sulcus, separating the anterior and posterior divisions of the insula, was identified and marked with thread. *b*, A horizontal cut, made through the same specimen, allows a view corresponding to section 6 of the reconstruction program as shown in the top row of Fig. 1. At the same time, a lateral view of the brain and the insular cortex can be seen, with the critical region on the precentral gyrus just anterior to the central sulcus.

the extent of their injuries. If this insular region is indeed reserved for articulatory planning, then overlapping of lesions in this second group of patients without apraxia of speech should demonstrate a sparing of this focal area.

Figure 1*b* shows the overlay of lesions in those patients without apraxia of speech. These lesions span essentially the same arterial distribution as the group of apraxic patients but spare one significant area; the very area which is consistently infarcted in patients with apraxia of speech (Fig. 1*a*, top) is entirely spared in those patients without the disorder (Fig. 1*b*, top).

Thus the role for the insula in articulatory planning is supported by a double dissociation. Every one of the 25 patients with apraxia of speech had a lesion encompassing this discrete region of the insula, whereas none of the lesions in the 19 patients without apraxia of speech involved this critical area. This new area of the brain associated with articulatory planning, as localized on section 6, corresponds to Talaraich coordinates $-41, -2, 10$ (ref. 5).

To determine the exact location of this articulatory planning area, a normal human brain was dissected and comparisons were made with the slices of the reconstruction programme (Fig. 2). Removal of the frontal, parietal and temporal opercula of the brain's lateral surface revealed the island of cortex underneath known as the insula. A small thread was placed in the central sulcus of the insula to mark anterior from posterior insular gyri. Sectioning the brain to compare to the same horizontal slice as the computerized lesion reconstructions revealed that the area of

interest lay on the precentral gyrus of the insula, directly anterior to the central sulcus as marked.

The results are relevant to a number of important issues. First, a specific lesion site for apraxia of speech has never before been described, to my knowledge. This has been due largely to the lack of agreement on terminology and diagnosis as well as inadequate lesion information. Some attempts to localize apraxia of speech have concluded that no specific cortical region controls the planning of articulation⁶. Others have suggested there may be as many as three different types of apraxia of speech, each associated with a different brain area⁷. At one time Broca's area was thought to be involved solely⁸ or in combination with lesions in other areas^{9,10}, but patients with lesions restricted to Broca's area were not found to have persisting apraxia of speech^{11,12}. Kertesz¹³ described ten cases of apraxia of speech with lesions confined to subcortical structures and concluded that these, as well as cortical structures, must be involved in speech praxis. Oral apraxia, a deficit in planning oral movements often found to coexist with apraxia of speech, was related to lesions in the left frontal and central opercula and anterior insula¹⁴. In general, authors have agreed that anterior structures, as opposed to posterior (temporal and parietal) lobes, are typically involved in apraxia of speech (refs 1 and 15, but see ref. 7), though no specific anterior area has been identified.

The second issue is that the functions of the insula, particularly of the precentral gyrus, have been poorly defined. The insula is considered part of the paralimbic cortex¹⁶ and has been implicated in visceral sensory functions (taste, olfactory and gastric sensations), motor functions (respiration and gastrointestinal activity), as a supplementary motor area (gross body movements also including lips, larynx and face) and a vestibular area (receiving projections from the dorsal thalamus)¹⁷. Recent evidence suggests that the insula may also function as a secondary somatosensory area. Recording sites in posterior insular cortex of the rhesus monkey responded to non-noxious somatic, visual, auditory and gustatory stimuli, suggesting an important role for this area in somatosensory processing¹⁸. Others have documented changes in cerebral blood flow to insular areas in response to vibrotactile stimulation of the feet and hands in human subjects¹⁹. Last, cardiovascular responses have been produced with stimulation to the insula in rats and in humans²⁰.

The insula has traditionally not been specified as important in the study of speech and language localization, possibly because of a historical trend which focused instead on other cortical regions for these functions, typically overlooking subcortical structures and insular cortex. One exception is a study²¹ in which electro-

BOX 1 Examples of articulatory errors in patients with apraxia of speech

Patient H.F. (attempting to say 'cushion')
 "Oh, uh, uh, /chookun/ uh, uh, uh, /dook/, I know what it's called, it's c-u, uh, no, it's, it's /chook/ /chookun/, no."
 Patient D.B. (repeating 'catastrophe' 5 times)
 "catastrophe, /patastrofee/, /t/ catastrophe, /katasrifrobee/ aw sh-- , /ka/ /kata/ sh-- , sh-- I don't know."

Patients with apraxia of speech will inconsistently misarticulate words and then struggle for the correct pronunciation in repeated trials. These errors may occur among 'islands of fluent speech'⁸ and appear less often in more automatic utterances such as expletives or common phrases. Changes in rate and prosody also occur, possibly as a result of the difficulty in articulation or as a method of compensation. Because these repetitions resemble the target word, the errors are not considered deficits in word retrieval and patients do not report difficulty in finding the word as much as in producing it. The disorder must also be distinguished from the different types of dysarthrias which are a result of weak or paralysed muscles that actually perform the articulation and are distinguished

TABLE 1 Demographic characteristics of the two patient groups

	Patients with apraxia of speech	Patients without apraxia of speech
Number of patients	25	19
Age	32–79 years	52–80 years
Education	8–18 years	8–18 years
Time after onset of stroke	1–14 years	1–11 years
Coexisting conditions: (per cent of patients in group)		
Bucco-facial apraxia	48%	0%
Limb apraxia	52%	0%
Dysarthria	40%	0%
Broca's aphasia	52%	0%
Global aphasia	12%	0%
Anomic aphasia	28%	26%
Wernicke's aphasia	0%	21%
Conduction aphasia	0%	11%
Unclassifiable aphasia	0%	5%
No aphasia	8%	37%

cortical stimulation to the insula during epilepsy surgery produced word-finding errors. However, identification of any particular region within the insula was not made. Another study²² describes a case with bilateral infarctions of the insula resulting in severe mutism of a month's duration, and a persistent sound-recognition deficit. This patient also had a severe bucco-facial apraxia and decreased fluency several months after onset, although auditory and reading comprehension as well as naming abilities were near perfect. Several authors have mentioned involvement of the insula in disorders such as conduction aphasia²³, and particularly Broca's aphasia, in which articulatory errors are prominent^{11,24–26}. A number of studies have mentioned increases in blood flow to the insula in tasks involving speech (see, for example, ref. 27), although none has identified any specific area within the insula in relation to articulatory planning.

The possibility that the precentral gyrus might serve as a preliminary processor to the initiation of articulatory movements raises questions about the functions of other discrete regions along this gyrus. The possibility that the insula might also subserve other types of movement planning, such as limb praxis or the articulation of sign-language gestures, is currently being explored.

The result reported here is important for models of cerebral localization that strive to localize language functions as well as other areas of cognition. Although complex cognitive behaviours may be more difficult to localize than motor or sensory functions, determination of specific aspects of language and cognition, coupled with the careful delineation of lesion site, can lead to a better understanding of whether or not these functions might be localizable in the brain. This, in turn, gives us more information about the neural mechanisms of language and cognition. □

Methods

Subjects. Forty-four patients met the following criteria. All had suffered a single left-hemisphere cerebrovascular accident (stroke) with no other history of neurological or psychiatric problems. The injuries had occurred at least one year before inclusion in the study to ensure that the observed speech and language deficits had stabilized. All patients had undergone CT or MRI at least 3 weeks (typically 4–5 years) after onset of their injury to guarantee distinct boundaries of the completed stroke. Patients were all right-handed and native English-speaking with normal hearing. Further demographic information is given in Table 1.

Diagnosis of apraxia of speech. This disorder is difficult to separate from the frequently coexisting effects of aphasia and/or dysarthria and must be diagnosed by a speech-language pathologist trained to recognize the difference. To be certain of the presence or absence of speech apraxia in this study, at least two certified speech-language pathologists were asked to make the diagnoses. This was done either by direct administration of the Motor Speech Evaluation²⁸ or by viewing a videotape of its administration and scoring blind to the other clinicians' diagnosis of the patient. Clinicians listened to patients' performance on rapidly alternating articulatory movements, repetitions

of single words differing in articulatory complexity, repetitions of sentences, samples of spontaneous speech elicited by the description of a picture, and readings of a passage of text. Assessments were based on four criteria measuring a pattern of articulatory behaviour as described by Wertz *et al.* (ref. 28, page 81): '(1) effortful, trial-and-error, groping articulatory movements and attempts at self correction, (2) dysprosody unrelieved by extended periods of normal rhythm, stress, and intonation, (3) articulatory inconsistency on repeated productions of the same utterance, (4) obvious difficulty initiating utterances'. Clinicians observed several instances of each of these criteria throughout the examination before making a diagnosis of apraxia of speech. These patients typically substituted one phoneme for another (usually on initial consonants), had greater difficulty with longer words or sentences, and greater difficulty with repetition than with reading aloud. Clinicians also rated the severity of the performance on a scale of 0 to 7, with '0' indicating no apraxia of speech and '7' reflecting a severe disorder. The mean severity rating for the speech apraxic patients in this study was 4.0. Patients diagnosed without apraxia of speech did not meet all of the above four criteria in their pattern of performance, and all received an overall severity rating of 0. Patients whose diagnosis could not be agreed upon were excluded from this study.

Lesion reconstructions. Lesions were reconstructed onto templates derived from the atlas of ref. 29, representing 11 horizontal slices through the brain at an angle of 0° to the orbital-meatal line.

Reconstructions were done by a board-certified neurologist (R.T.K.) who was particularly experienced in CT and MRI and a co-designer of the reconstruction software. Lesions were not simply traced, but reconstructed in relation to neuroanatomical landmarks to compensate for any discrepancies in scanning angles. Both CT and MRI scans were used, as available, from patients' radiology files. In 89% of the cases, CT scans were used, including 23% of all patients who had both CT and MRI scans. MRIs alone were available from the remaining 11%. Lesion boundaries were entered into a PDP 11/45 minicomputer via electronic bitpad and overlays were derived from the reconstruction software⁴. Determinations of the presence or absence of apraxia of speech were made blind to knowledge of lesion localization, just as lesion reconstructions were made blind to the diagnosis of the behavioural deficit.

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