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Beyond Broca's and Wernicke's Areas:
# A New Perspective on the Neurobiology of Language

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Brain-based discussion of language has classically centered around models focused on Broca's and Wernicke's areas. Recent neurobiological research indicates that such models may be oversimplified. The present paper attempts to propose a model in which a far greater number of brain structures are involved in language functions. To demonstrate this model, three areas of the brain rarely associated with language, the anterior cingulate gyrus, the prefrontal cortex, and the basal temporal language area (fusiform gyrus) are examined. Recent neurobiological research linking these areas to language function will be reviewed to illustrate that a whole-brain view of language is both more feasible and better supported by data than the idea of a language-specific brain system, such as the Wernicke-Geschwind model.

INTRODUCTION

Localization theory, which advocates that various abilities are mapped to specific anatomical structures in the brain, was first proposed in the early nineteenth century by Gall and Spurzheim (1810). This theory was applied to language abilities in 1861 when Paul Broca attributed speech to a frontal portion of the brain's left hemisphere, an area that became known as Broca's area. About ten years later, Karl Wernicke correlated a deficit in comprehension and semantic meaning with brain damage in an area of the left temporal lobe now known as Wernicke's area. Wernicke composed a theory of language based on interaction between various sensory areas (such as auditory areas for hearing language) in the brain with Wernicke's and Broca's areas

during language perception and production (Mayeux & Kandel, 1991). Study of the brain and language has continued to focus heavily on these two areas and has produced language theories based on the Wernicke model (Geschwind, 1965; Penfield & Roberts, 1959). In this model, the process of naming a visually sighted object begins by the transfer of information from the eyes to the visual cortex. From there the information is taken to the angular gyrus and then to the adjacent Wernicke's area. Here the visual information becomes a phonetic representation. This representation is sent through the
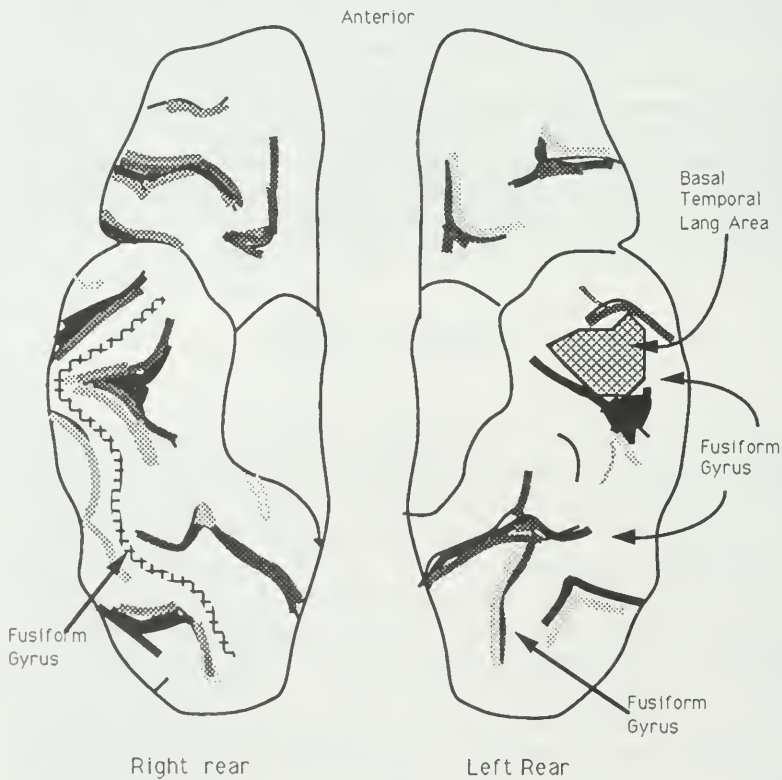
UNDERSIDE OF THE BRAIN

Figure 1. The diagram of the right side of the brain shows a hatched line that follows the fusiform gyrus down the underside of the brain. The gyrus is pointed out by arrows on the diagram of the left brain. The shaded area indicates the region of the fusiform gyrus known as the basal temporal language area.

arcuate fasciculus to Broca's area, where it is conveyed to the motor cortex to initiate articulation (Mayeux & Kandel, 1991).

Although Wernicke's model and subsequent models have contributed to our current understanding of brain lesions and language deficits, they do not necessarily explain the production of language in normal individuals. While the deficits can be correlated with damaged anatomical structures, the size and precise location of lesions is not exactly the same in all cases. Thus, corresponding generalizations to language production may be oversimplified. The model indicates that two areas of the cortex specialized for language, along with a few accessory areas, are involved in language production. Recent neurobiological research indicates that a new view of language may be hypothesized, one far more complex than the traditional Wernicke-Geschwind model involving Broca's and Wernicke's areas along with a few connecting structures (Geschwind, 1965; Damasio & Geschwind, 1984). A more plausible model would incorporate a larger number of brain systems into language, rather than simply one language-specialized system.

Recent technological developments have led to new methods of investigation that are non-invasive and do not require a language-deficient subject. One such method, Positron Emission Tomography (PET), is a brain imaging technique that allows researchers to make correlations between function and anatomy (Phelps, 1991a). PET determines the metabolic rate and the relative amount of blood flowing to a particular brain region, both of which are measures of the relative activity of that structure. This technique has allowed researchers to determine which parts of the brain are active during normal functions, such as attention, audition, or eye movement (Phelps, 1991a). Because of the increasingly high resolution of the imaging, the activity of a number of structures located throughout the brain may be simultaneously observed (Phelps, 1991b).

Use of PET, coupled with results from excision and electrical stimulation studies[1], has allowed researchers to identify whole neural systems involved in brain activities, such as language (production and comprehension). The resulting data indicate that numerous processes are involved in language production and acquisition and that each of these processes involves a variety of distinct yet interconnected structures. For example, for a second language learner to generate a sentence fluently requires the long term memory storage and retrieval of vocabulary, as well as internalized knowledge regarding the

application (and operationalization) of grammatical rules. A process known as long term potentiation, originating in the hippocampus and related structures, seems to lead to the memory needed for vocabulary storage. In addition, rapid retrieval and use of grammatical knowledge may be viewed as a procedural skill, thus involving the procedural knowledge memory system of the cerebellum in language (see Robbins, this volume).

Language is not a function that the cerebellum was expected to have and yet the data seems to indicate that it does have a role. Previous reports on the functions of the cerebellum focussed on the motor coordination role of that structure. Likewise, recent neurobiological data seem to implicate three areas previously unsuspected of playing a role in language. The fusiform gyrus appears on the underside of the brain and may not have been accessible to surgeons for lesion studies in times past. Known for its role as an association area, the anterior cingulate has previously been assigned the function of relaying sensory information to other areas of the cortex. The prefrontal cortex has long been associated with cognitive functions and planning, but never with language. Linking this region with language,indicates that not only this region, but any that play a role in the cognitive functioning of humans, may be involved in language. Because each of these regions is also known to play a role thought to be unrelated to language, they are excellent candidates for demonstrating the whole-brain perspective of language.

ANATOMY OF THE FUSIFORM GYRUS

The fusiform gyrus (also known as the lateral occipitotemporal gyrus) is a longitudinal fold of cortex located on the underside of the temporal lobe. Connections of this particular gyrus are not well established. A known link occurs between the fusiform gyrus and the area near the angular gyrus, an area adjacent to the traditional Wernicke's area (Bogousslavsky, Miklossy, Deruaz, Assal, & Regli, 1987). The basal temporal language (BTL) area, the focus of discussion here, is a small region located on this gyrus (see Figure 1).

Basal Temporal Language Area

Wernicke's area is generally accepted as the location where processing for language comprehension occurs. Electrical stimulation studies done by Luders and his colleagues have shown that the anterior portion of the fusiform gyrus also plays some role in language comprehension. They have named this small section the basal temporal language area (BTL).

Luders and colleagues originally located the area through a case study and then verified his findings in a more extensive study. In the case study, a man with intractable complex partial seizures was evaluated in preparation for surgical treatment of epilepsy (Luders, Lesser, Hahn, Dinner, Morris, Resor, & Harrison, 1986). The man tested normal for intelligence on the Wechsler Adult Intelligence Scale[2] and displayed no physical ailments other than epilepsy. A Wada test[3] determined that he was left hemisphere dominant for the computational aspects of language.

Arrays of subdural electrodes were surgically implanted over the lateral and basal surfaces of the temporal lobe in the left hemisphere to identify the position of the epileptogenic focus in the left temporal lobe. Stimulation of the electrodes in the lateral temporal region over Wernicke's area produced speech interference, defined as an inability to read a text aloud. Writing was also inhibited. This same type of speech deficit was observed when the basal temporal region was stimulated. The patient was unable to comprehend either spoken and written language and could not repeat words spoken to him. Moreover, the patient could not write words he had been instructed to write prior to the start of stimulation. Essentially, a global aphasia was produced by stimulation of BTL. Luders and colleagues determined the aphasia to be a language specific interference by eliminating the other possible causes for speech arrest. The possibility of stimulation producing a seizure was eliminated, as no other clinical signs of a seizure were evident and none of the widespread electrical activity that usually accompanies a seizure was detected. The speech arrest was not due to a negative motor effect (motor inhibition due to stimulation), as the patient was still able to produce rapid alternating movements in his hands and lips. Nor did the stimulation produce a general processing interruption, as the patient was still able to memorize complex geometric designs and draw them from memory during stimulation. Luders

and colleagues concluded that they had happened upon a true language area.

Luders and his colleagues then performed a more extensive electrical stimulation study of 22 epileptic patients (Luders, Lesser, Hahn, Dinner, Morris, Wyllie & Godoy, 1991). In eight of the 22 patients, a basal temporal language area was identified, compared to 15 of 22 for Broca's area and 14 of 22 for Wernicke's area. In the eight patients who exhibited a basal temporal language area, the language deficit was elicited with stimulation only in the dominant hemisphere, never in the nondominant temporal lobe. Moreover, the degree of language interference, as measured by the ability to read aloud, was found to increase with the strength of the stimulation. Three of the 8 patients were tested in more detail to determine the extent of their aphasia. Two of the patients could not repeat words during stimulation; the third was able to communicate only by gestures. Verbal comprehension as tested by the Token test (following simple one and two-step commands) was inhibited by stimulation to some degree in all three. All three patients were also unable to name objects presented to them during stimulation. The patients all had severe agraphia (i.e., inability to write) during stimulation as well. As before, the language interference could best be characterized as a global aphasia in all the patients.

To verify the specificity of the language interference, several other functional tests were conducted. Using Koh's block tests (Stone, 1985) to examine intellectual function in two patients, Luders and colleagues found that they were able to perform relatively complex tasks without any sign of inhibitions. Motor activity was determined to be unaffected because rapid alternating tongue movement was possible (no negative motor effect). Patients also performed complex nonverbal tasks without difficulty and facial recognition posed no problems for the patients either. The occurrence of circumlocutions and the ability to communicate with gestures points to intact mental functioning, ruling out a disturbance of consciousness. These tests suggest that the language inhibition was not due to intellectual dysfunction, motor inhibition, or epileptiform disturbances of consciousness

Luders and colleagues were able to identify the exact location of the basal temporal language area by controlling which electrode in the implanted array was used during the stimulation. X-rays and surgical inspection confirmed the positions of the electrode. The basal temporal area began about 3 to 3.5 cm from the anterior tip of the temporal lobe in all cases and varied at the

posterior end of the fusiform gyrus between 4 to 7 cm from the temporal pole (see Figure 2). The variation in size of the basal temporal area was not addressed by Luders and colleagues in reference to determining language loss.

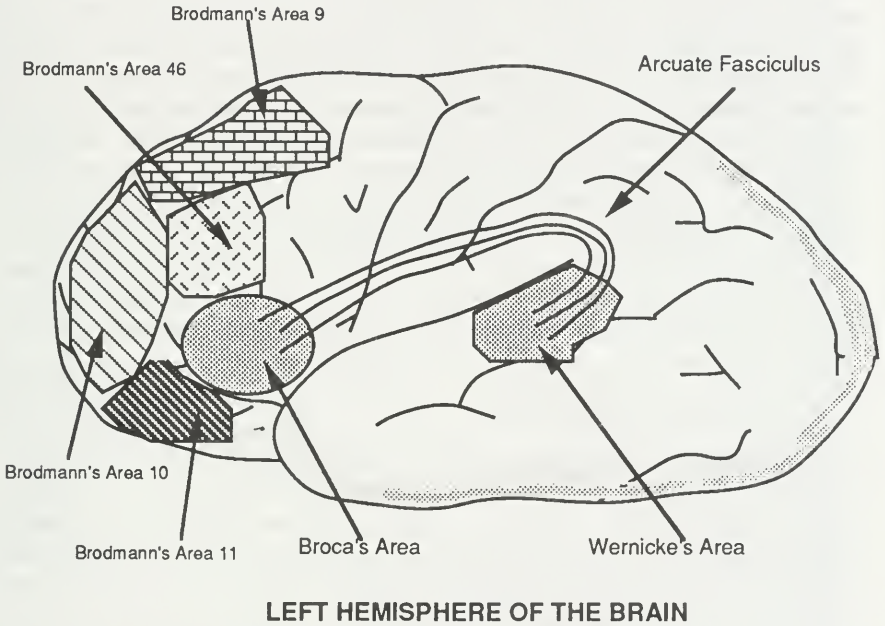**LEFT HEMISPHERE OF THE BRAIN**

Figure 2. Diagram of the lateral (outer) side of the left side of the brain. The arcuate fasciculus is a bundle of fibers that extends from the temporal lobe, near Wernicke's area, curves around the angular gyrus and travels forward to the prefrontal cortex, near Broca's area. The prefrontal cortex is indicated as Brodmann's areas 9, 10, 11, and 46.

Three of the patients required removal of the basal temporal language area to treat their epilepsy and in two cases, no verbal deficit was detected postoperatively. In the third case, a slight temporary aphasia occurred that disappeared six months postoperatively.

THE FUSIFORM GYRUS (BTL AREA) IN LANGUAGE

The presence of a third language area is a surprising development that certainly requires modification of the Wernicke-Geschwind model for language processing, particularly because stimulation in the basal temporal area and Wernicke's area produced similar types of effects. A negative motor area (region of the brain which, when stimulated, causes inhibition of motor activity) overlaps parts of Broca's area and stimulation in non-motor regions within Broca's area produces similar effects. Noting that language inhibition was not produced in stimulation of any part of the inferior temporal gyrus, Luders and colleagues (1986) concluded that the basal temporal area is not merely a previously undetected portion of Wernicke's area, but a separate entity that may work in conjunction with the classical language areas. He also speculates that the expressive aphasia associated with Broca's area could be due to lesions in both the language and motor areas in that location while the communicative aphasia associated with Wernicke's area occurs because damage is confined only to language areas (Luders, Lesser, Dinner, Morris, Wyllie, & Godoy, 1988). In other words, if only the language areas within Broca's area were damaged, a comprehension aphasia would result and not an expressive one. Since similar deficits are produced in the three language areas, he inferred that they all work in conjunction and that an extensive direct connection must exist between these areas. The bundle of fibers called the arcuate fasciculus does indeed originate in the temporal lobe and travel back towards Wernicke's area (see Figure 2) before proceeding forward into the prefrontal cortex near Broca's area (Geschwind, 1979). Conduction aphasia, an aphasia involving fluent speech, poor speech repetition abilities and intact auditory comprehension seems to be an intermediate aphasia, having characteristics of both Broca's and Wernicke's aphasias. Anatomical evidence indicates that this third aphasia is caused by arcuate fasciculus lesions, disrupting the communication between Wernicke's and Broca's areas (Damasio & Damasio, 1980), as predicted by the Wernicke's original model (Geschwind, 1964; Damasio & Geschwind, 1984). A connection between the basal temporal region and Wernicke's area has not yet been identified, but Luders and colleagues hypothesize that it exists. They cite Rosene and Hoesen's (1977) work showing the existence of direct connections between the hippocampus and the cortex in the frontal and

temporal lobes as evidence for this possibility. Connections between the fusiform gyrus and the angular gyrus may also provide a possible indirect connection between Wernicke's area and this basal temporal language area.

If these three brain areas work in conjunction, the question arises why Broca's and Wernicke's area were able to be identified so much more frequently than the basal temporal language area. The surgical data suggests that the basal temporal region is not a crucial area since each of the three patients with a surgically removed basal temporal area demonstrated no postoperative aphasia, save one in which it disappeared after six months (Luders, et al., 1991). It is possible that the function is bilateral and that removal of the dominant hemisphere causes previously existing connections on the nondominant hemisphere to be reinforced, a process which requires time. It would be interesting to see whether a bilateral resection of the basal temporal region would reproduce the effects of electrical stimulation. Electrical stimulation tests on the basal temporal region of the nondominant hemisphere after recovery from resection of the basal region of the dominant temporal lobe may also provide that information.

The data suggest that a basal temporal language area definitely exists in some patients. Because it is not seen in every patient, the part it plays in the whole scheme of language generation remains partially unsure. Because the data indicates that there is no problem with the input (visual or auditory) stage, perhaps the interference lies in the processing stage, where the patients "had no access to the verbal engrams which establish the link between symbolic verbal material and the corresponding nonverbal expressions" (Luders et al., 1991, p. 751).

ATTENTION (DETECTION) AND LANGUAGE
(The Anterior Cingulate)

One of the anterior cingulate's primary functions is in attention. In order to see the relevance of this structure to language, one must first understand the importance of attention to language processes. Thus, the role of attention in language will be addressed before a description of the anterior cingulate's anatomy is presented.

In addition to the processes mentioned above, adult second language learners also use conscious self-monitoring when

learning the second language, such as when the learner speaks, listens or writes (Chamot, Kupper, & Impink-Hernandez, 1988a, 1988b; Rubin, 1981). For example, in response to a verbal message, several steps must ensue. In a greatly simplified scenario, the auditory signal must first be filtered from all other stimuli (see Sato & Jacobs, this volume). The auditory signal is then processed in the brain to associate meaning with the sounds. Using the associated meaning, cognitive planning must then occur to determine the appropriate response to the auditory message. After the planning occurs, the appropriate brain areas are recruited to generate the response. Monitoring of the output is also necessary, particularly in nonfluent learners, to produce grammatically correct responses to the heard speech. This monitoring requires that attention be focussed on the appropriate stimuli, a focusing which has been shown to be a function of the anterior cingulate. The anterior cingulate may then be viewed as a participant in the self-evaluation process. The prefrontal cortex has been implicated in cognitive planning and organization and thus consequently also seems to play an important role in language. Although children seem to use these cognitive functions in first language acquisition, the prefrontal cortex is not completely developed during the time of the acquisition, thus complicating the picture. Neurons in the prefrontal cortex (specifically pyramidal cells in cortex layer III) continue to enlarge, both in cell body size and branching of the neuron projections, until approximately ten years of age (Mrzljak, Uylings, Van Eden & Judas, 1990). Neurons in the prefrontal cortex are also among the last neurons in the brain to myelinate (coat themselves with a fat-like substance) (Fuster, 1980). Because the extensiveness of neuron projections and myelination facilitate information exchange and, thus, processing, the prefrontal cortex cannot be considered fully functional until maturation is complete. Correspondingly, the functions of the prefrontal cortex are more easily defined in the adult second language learner (whose cortex has completed maturation). Thus our discussion will focus on the role of the prefrontal cortex and anterior cingulate in second language learning and production, rather than first language acquisition.

The acquisition and production of a second language in adults involve a general attention system. For the purpose of this paper, attention is defined as "the ability to select or focus on a small fraction of the incoming sensory information" (Corbetta, Miezin, Dobmeyer, Shulman & Petersen, 1991). Within this

definition, attention may be parsed into three functions (Posner & Petersen, 1990): 1) orientation to sensory information, 2) detection of specified information for processing, and 3) maintenance of alertness. Only detection will be dealt with here since it is involved in language and self-evaluation.

Detection is defined as the identification of a targeted item (Posner & Petersen, 1990). That target includes information in stored memory as well as sensory data. In the process of language production and acquisition, detection provides the means by which a learner can monitor his language production. For example, using Bialystok's (1978) model of second language learning, consider a nonfluent adult learning Spanish as a second language. When speaking, the learner will consciously identify the subject of the sentence and then mentally review a list of verb forms to find the appropriate one, before, during, and after generating the sentence. Krashen's (1981) monitor model posits the use of conscious self-evaluation when actively studying to learn a language, but not during "acquisition," the unconscious learning of a language. Detection may then be viewed as monitoring in Krashen's monitor model. This detection also allows the learner to evaluate the responses of the listener.

The generalized attention system, under which detection falls, may be viewed as two smaller entities, the posterior and anterior attention systems (Posner & Petersen, 1990). It is the anterior system that plays a key role in detection during cognitive functions, which include language. Within the anterior attention system, one of the main players is the anterior cingulate, thus, it will be the focus of the discussion on attention (detection) and language.

ANATOMY OF
THE ANTERIOR CINGULATE GYRUS

The anterior cingulate gyrus is an outward fold in the cortex, located on the medial surfaces of the frontal lobes in both hemispheres of the brain. The cingulate gyrus curves around the corpus callosum, the bundle of fibers connecting the two hemispheres (See Figure 3).

The distinction between the anterior and posterior regions of the cingulate is important since the two regions have differing input connections (Vogt, 1985) and functions (Vogt, 1987). The

posterior cingulate is involved in pain and reactions to noxious stimuli. The anterior cingulate is the portion of the gyrus to which the language functions are being ascribed.

The anteriomedial and mediothalamic nuclei provide the majority of thalamic input for the anterior cingulate (Vogt, 1985). The anterior cingulate also receives input from higher order sensory cortex (not primary sensory cortex) and sends output to the prefrontal cortex (Kupfermann, 1991). Existence of connections between the prefrontal cortex and the anterior
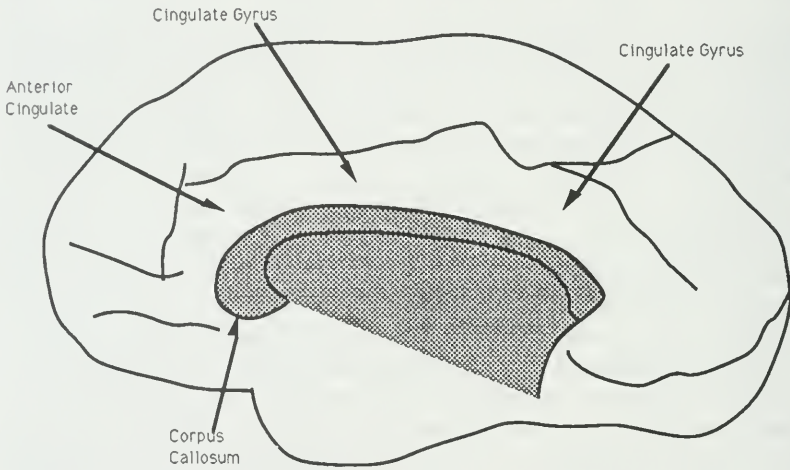
MEDIAL VIEW OF THE BRAIN

Figure 3. Medial View of the right side of the brain. The anterior cingulate is the fold of brain tissue just above the corpus callosum. The anterior portion of the cingulate is pointed out above.

cingulate would increase the possibility that they affect each other during language processing, if that is shown to be a function in either location. As the main input to the anterior cingulate, the mammilothalamic tract will also prove to be important. Consequently, the mammilothalamic tract and the connection with the prefrontal cortex are central to the discussion presented below.

THE ROLE OF THE ANTERIOR CINGULATE
IN DETECTION/SELECTION

Regional blood flow in the brain has been shown to increase in the anterior cingulate during single word association tasks (Petersen, Fox, Posner, Mintun & Raichle, 1988). These tasks required normal subjects to generate a verb semantically related to a visually presented noun (e.g., "eat" when presented with "food"). Subjects were also asked to monitor lists of words, identifying those belonging to a particular semantic category (e.g., searching a word list for different foods). PET data indicated activation of the anterior cingulate in both tasks. Interestingly, the amount of activation seen in the anterior cingulate was found to be greater for lists containing many words from the selected categories (Petersen et al., 1988; Petersen, Fox, Posner, Mintun & Raichle, 1989). Activation in a part of the left prefrontal lobe was also observed. However, similar blood flow increases were not seen during visual presentation alone (no response required from the subject), nor during an output task in which the subject verbally repeated the word presented on the screen.

The verb generation task included speech (reporting the verb), visual processing, and semantic association between a verb and a noun and possibly some type of grammatical computation in identifying the part of speech. The amount of activation in each task was determined by subtracting the numerical values of activation determined by PET from the PET results of nearly identical tasks, differing only in one aspect of the task. For example, PET values of a person viewing and reading a printed noun were subtracted from a PET of one viewing a noun and speaking an associated verb. The semantic association is the only difference between the two tasks (Petersen et al., 1989). The results showed that the anterior cingulate and lateral prefrontal cortex were active and suggests that they were involved in that association. The anterior cingulate was also implicated in the detection and selection of words because its activation only increased on the word lists tasks with more target words (Posner, Petersen, Fox & Raichle, 1988; Petersen et al., 1988; Petersen et al., 1989). In contrast, the lateral prefrontal cortex activation did not vary with the number of targets in the lists.

The fact that activation of the anterior cingulate is stronger in searching lists with more targets strongly suggests that the cingulate is involved in detection. The only difference between the tasks of searching a list with fewer targets and searching a list

with more targets is the detecting of the targets and generating responses, the latter also being considered a function of the anterior cingulate in detection or "attention for action" (Posner et al., 1988), meaning that the anterior cingulate selects a processing center or a course of response for the stimuli.

Pardo, Pardo, Janer, and Raichle (1990) have also studied the anterior cingulate in a verbal task. Their task was constructed under the Stroop attentional conflict paradigm in which subjects had to resolve the interference between word reading and color naming (Pardo et al., 1990). For example, subjects were presented the word "red" in green letters and asked to name the color of the letters as quickly as possible. Although the Stroop task is different from the Petersen, Fox, Posner, Mintun, and Raichle (1988) experiments, both tasks require a shunning of the tendency to read the noun presented while generating another word. Although it does not require a selection/detection of external data, the Stroop task demands selection of the relevant processing center to which the information is sent (Pardo et al., 1990). PET data from these Stroop conflict tests show the greatest activation to be in the anterior cingulate. This lends support to the idea that the anterior cingulate participates in the selection of a processing center or cognitive operations.

PET scans performed by Corbetta, Miezin, Dobmeyer, Shulman, and Petersen (1991) have indicated that the anterior cingulate is active not only in language specific tasks, but also during tasks requiring complex cognitive functioning. Their experiments examined two situations: a selective attention and a divided attention task. In the selective attention task, subjects were required to detect the changes in a single, specific feature (size, color, shape or speed) of moving blocks in visual screen. Other features were either constant or also shifting during the tests. Alterations in features not specified by the researchers were to be ignored during the selective attention task. In contrast, the divided attention task required detection of a change in any feature; no feature was specified for the subject to focus on.

A number of brain regions were activated in both tasks; but only in the divided attention task was the anterior cingulate activated. The prefrontal cortex was also activated in the divided task. The data indicate that, cognitively, the brain views the two tasks "as qualitatively different" (Corbetta et al., 1991, p. 2398). The selective attention task necessitated the maintenance of a focus on a specified feature. However, the divided attention task did not involve a preset focus, but rather imposed greater demands

in the coordination and comparison of information. Corbetta, Miezin, Dobmeyer, Shulman, and Petersen (1991) surmise that all the sensory information regarding the various features is processed in the prefrontal cortex, which then sends data to the anterior cingulate for response selection.

That the anterior cingulate functions preferentially in cognitive tasks was demonstrated in an experiment by Pardo, Fox and Raichle (1991). The tasks involved were solely sustained attention tasks for somatosensory stimuli (e.g., noticing touches on a toe or changes in the intensity of a light). The authors concluded that the task did not require use of "high-level processing selection systems necessary for the analysis of complex targets" (p. 63), and thus did not require the anterior cingulate's usage.

Raichle (1990) has noted that activation in the prefrontal cortex and the anterior cingulate during Petersen, Fox, Posner, Mintun, and Raichle's (1989) verb generation task was only found when the task was first presented to the subjects. As a "new" task, it required active attention. However, after the task had been rehearsed (e.g., practicing the generation of verbs for one specified list of nouns and being tested for the same list), activation of the prefrontal cortex and anterior cingulate was no longer seen. In other words, after the task had been automated by continuous practice, the attention was no longer needed. Language acquisition is similar; once the grammatical structures are "acquired", they become automatic. The anterior cingulate may have a role in language acquisition through detecting features or selecting responses when the situations are still novel. Processing for the responses occurs elsewhere when the responses have been practiced enough for the cerebellum to ingrain them into procedural memory.

ANATOMY OF THE PREFRONTAL CORTEX

The prefrontal cortex is located in the anterior lateral portions of the cerebral cortex, corresponding to Brodmann's (1909) areas 9, 10, 11 and 46 (see figure 1). The connectivity of the prefrontal cortex extends throughout the brain. This high degree of connectivity would allow it to play the role of integrator of sensory information in the divided attention task mentioned above (Corbetta et al., 1991). For the present purposes, the most

important connections are with the thalamus and the anterior cingulate.

COGNITIVE FUNCTIONS OF THE PREFRONTAL CORTEX

Lesion studies of patients have indicated that the prefrontal cortex is involved in cognitive planning. Lesions in the prefrontal area lead to a disorder termed "central motor aphasia" (Goldstein, 1948), which is characterized by slowed spontaneous speech and a low level of expressivity. Jackson (1915) reports that the patients speak in short, simple sentences, almost as if their ability to use complex sentences (e.g., those with subordinate clauses) is reduced. Fuster (1985) concludes that these lesions impair the ability to organize complex language and to sequence the shorter clauses for the longer sentences. Stuss and Benson (1984) report four main behavioral deficits as a result of prefrontal damage: a) an inability to use knowledge about a task to complete a task, b) inability to monitor behavior for errors and to use the errors to modify behavior, c) inability to establish a set (frame of reference), and d) impaired ability to perform sequential tasks. Citing the connections between the frontal and prefrontal cortex, McGrath (1991) speculates that breakdowns in the looping connections between the two areas cause the observed impairment, much of which affects the quality of language produced.

Novoa and Ardila (1987) report that patients with prefrontal lesions retain the formal aspects of language such as lexical and phonetic knowledge. However, patients were slow with verbal tasks and showed signs of perseveration, free association of ideas, and noticeable failures in verbal memory. Consequently, Novoa and Ardila suggest that the lesions cause loss or impairment of the capacity to elaborate, or express decisions about language.

A recent study by Kelly, Best and Kirk (1989) on the reading abilities of boys also implicates the prefrontal cortex in problem solving and selective attention. They examined a number of cognitive functions considered to be exclusively the domain of the prefrontal cortex and some functions considered to be the domain of the posterior cortical areas. The subjects of their study were boys who either were able to read (control group) or had

been identified as having difficulty learning to read. They found that those with a hindered ability to read or to learn to read showed a deficit in prefrontal functions. These boys did not consistently use new information to reformulate hypotheses in a problem solving task, nor were they able to maintain attention to certain aspects required by the tasks, such as color of the letters in the Stroop test (see above). They conclude that the "reading disabled youngsters have difficulty with cognitive processes involving sustained attention, inhibition, set maintenance [keeping a frame of reference], and flexibility in generating alternative hypotheses" (p. 289).

Although the above research indicates that the prefrontal cortex is involved in planning and using feedback in planning responses, recent PET evidence indicates some language-specific functions may be attributed to the prefrontal cortex as well. In the divided attention, but not the selective attention, task mentioned above (Corbetta et al., 1991), the prefrontal area was identified as an active area along with the anterior cingulate. Corbetta, Miezin, Dobmeryer, Shulman, and Petersen, (1991) attribute processing for complex-tasks to this area because it is very close to the areas found to be active in the semantic association tasks of Petersen, Fox, Posner, Mintun, and Raichle. (1988).

Petersen, Fox, Snyder, and Raichle (1990) have also presented evidence that the prefrontal cortex participates in language functions. Their PET scan study indicates that the prefrontal cortex is active when real words are presented visually, while meaningless symbols or nonword-like strings (e.g., sweed) do not cause similar activations. Petersen, Fox, Snyder, and Raichle (1990) argue that this area is involved in semantic association since the word form is similar in word-like strings of letters and true words, the only difference being the association of a meaning with the word and none with the word-like form.

The available data on the prefrontal cortex indicates that it is involved in planning cognitive tasks and in evaluating behavior. PET studies indicate a semantic association function as well. In relation to adult second language acquisition then, the prefrontal cortex may participate in planning and editing language from sentence level grammar up to cohesion in discourse (McGrath, 1991). This planning and editing function can provide a plan for evaluation which both it and the anterior cingulate may perform. Such an evaluation could then serve as the criteria that the anterior cingulate uses to determine the next area in the brain where further processing will occur (e.g., the motor areas for producing a

spoken reply to a call). The prefrontal planning role would only be in effect during the acquisition of the second language in adults since automating some of these grammar and discourse plans due to constant practice would relate responsibility of their performance to the cerebellum, to which both the prefrontal cortex and the anterior cingulate are connected (Leiner, Leiner & Dow, 1989).

SYNTHESIS

The fact that language-related functions can be localized in these three previously unrelated structures indicates that a whole-brain view of language may be in order. If the BTL area, the prefrontal cortex, and the anterior cingulate have long remained unassociated with language functions, the probability that other areas of the brain which contribute to language could also go unacknowledged by neurolinguists is very high. While the Wernicke-Geschwind model has proved useful in language/brain research, current neurobiological knowledge has shown it to be oversimplified. Because the Wernicke-Geschwind model presupposes a language-specific system in the brain, it automatically narrows the focus to brain regions near or directly related to Wernicke's or Broca's area. It thus directs research away from areas in which lesion-caused language deficiencies have not been noted yet, areas which may later prove to be crucial to language research.

Although the existence of areas outside the Wernicke model clouds the picture for explaining language, it points to a wide range of opportunities for further research in the brain/language field. The possibilities of identifying brain regions active in language and yet traditionally associated with other functions, such as the amygdala which functions in emotion (Schumann, 1990), hold out the chance that identification could lead to a greater understanding of the nature of second language learning and production, and even language itself.

NOTES

[1] In electrical stimulation studies, electrodes are implanted in the brain over the area to be studied. Application of an electrical current there disrupts the normal electrical activity of the neurons and thus inhibits their functioning. Behavioral correlations to these structures can be made during stimulations, which, in effect, produce a "temporary" brain lesion.

[2] The Wechsler Adult Intelligence test measures cognitive functioning.

[3] The Wada test involves injecting sodium amytal into the blood supply of either the right or the left hemisphere of the brain. Since it is a barbiturate and will slow down normal brain functions, sodium amytal determines which side of the brain is language dominant by identifying the hemisphere in which language functions are hindered upon injection.

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