Hickmann, M. (1986) Psychosocial aspects of language acquisition, in P. Fletcher and M. Garman (eds) *Language Acquisition* (2nd edn). Cambridge: Cambridge University Press, 9–29.

Jakobson, R. (1941, 1968) *Child Language, Aphasia and Phonological Universals* (trans. A.R. Keiler). The Hague: Mouton. (First published, 1941, as *Kindersprache, Aphasie und Allgemeine Lautgesetze*. Stockholm: Almqvist and Wiksell.)

Trott, K., Dobbinson, S. and Griffiths, P. (eds) (2004) *The Child Language Reader*. London: Routledge.

4.1 LORAINE K. OBLER and KRIS GJERLOW

How We Know What We Know about Brain Organization for Language*

Introduction to Reading 4.1

This reading contains potentially unfamiliar terms such as:

- *ipsilateral* (meaning 'on the same side of the body', 'opposite of *contralateral*')
- *lesion* (area of damaged (brain) tissue)
- *sylvian fissure* (a nearly horizontal fissure that can be seen in Figure 4.1.1; the large brain area below it is called the *temporal lobe*).

There is mention in the reading of *lateral dominance* (= one side of the brain leading for certain processes). Some background explanation on this is presented in the remainder of this paragraph and the next one. Mostly, the nerve connections between brain and body cross over to the opposite side, so the left-hand side of the body is linked to the right-hand side of the brain and vice versa, via contralateral connections. The ears, however, also have some ipsilateral connections (see the first bullet point above), though they are not as strong as the contralateral connections. The left–right split for the eyes works differently: sensory input from the *right visual (hemi)field* (= the right-hand half of what you can see) is transmitted from both eyes to the left-hand side of your brain, and vice versa for the left visual (hemi)field. The big top part of the brain, hanging like a mushroom cap over the mid-brain and brain stem, is called the *cerebrum* and is separated into a left half and a right half, the *left* and *right (cerebral) hemispheres*. Each hemisphere has its own blood supply. A big bundle of nerve fibres called the *corpus callosum* connects the two hemispheres.

It was noticed long ago that language and speech disabilities following strokes (sudden disruptions to the brain's blood supply) or head injuries often went with weakness in the right half of the body. Starting in the nineteenth century, post-mortem studies began to show that lesions were often in the left cerebral hemisphere of people who during their lifetime had been afflicted by various language difficulties. In most people – even most left handers – the left cerebrum is the dominant one for language.

Different parts of the brain perform different language functions. For instance, regions above the sylvian fissure (see above) and towards the front tend to be involved in output, while areas around the sylvian fissure and towards the rear are mainly for comprehension. Such specialisation is termed *localisation*.

ILU 11

* 1999, reprinted with permission from *Language and the Brain*. Cambridge: Cambridge University Press, Ch. 3, 27–36.

In the last quarter of the twentieth century, scanning techniques made it possible to discover where there were lesions in the brains of living people, so that any speech and language disabilities could be related in detail to different sub-regions of the language-dominant hemisphere. Dynamic scanning methods have been developed to monitor blood flow, oxygen use and electrical activity in the brain, which can be correlated with particular language tasks that subjects are carrying out at the same time.

For psycholinguists, the excitement of these techniques is that they point to the functional units that comprise our language-using ability, the ways that the sub-functions interlock, and the relative timings involved in making and understanding utterances.

LEFT-HEMISPHERE DOMINANCE FOR LANGUAGE

The search for localized brain centers for speech and language has a long and interesting history. The first group of neurologists to search for an area of the brain dedicated to language function were the phrenologists of the early nineteenth century [. . .]. Proponents of this school of thought believed that particular talents or personality traits manifested themselves in increased development in particular cortical areas with subsequent effects on the actual shape of the cranium or skull. Close examination of the skull, they believed, could lead to an understanding of the inner person. The phrenologists, such as Gall in England, Spurzheim in Germany and Bouillaud in France, believed the language faculty to be located in the two frontal lobes. In fact Bouillaud went as far as to offer a prize to anyone who could find a patient with linguistic deficits and no frontal lobe damage! There was some disagreement among phrenologists as to whether there was a single language faculty or perhaps, as Gall suggested, one center for the memory of words and another for articulate speech (Brown and Chobor 1992).

Data from brain damage

As early as 1836, John Abercrombie, a prominent Scottish physician, published data from which the association of left-brain damage with linguistic deficits was clear. As Hans Forstl (1991) points out in his review of Abercrombie's work, it was probably a reaction to the rather fanciful drawing of conclusions in phrenology that led Abercrombie to publish his observations without drawing attention to the obvious conclusion of left-hemisphere dominance for language.

More often cited as the first linking of the left hemisphere to language is the 1836 paper of Marc Dax, 'Lesions of the Left Half of the Brain Associated with the Loss of Signs of Thought', which represented the results of Dax's study on a large series of brain-injured patients. Forstl (1991) attributes the fact that this significant work was never published to the strength of the phrenological camp.

In fact it is the neurologist/anthropologist Paul Broca who is credited with discovering, and reporting in his 1865 paper, that language loss after brain injury was far more common after left-sided injury than after right-sided injury. More recent studies suggest that approximately 97 per cent of the population has language represented predominantly in the left hemisphere. Of the remaining 3 per cent, most are left-handed. Since we estimate that some 10 per cent of the population is left-handed, this means that the majority of left-handed individuals also have language represented in their left hemisphere.

How do we know that 3 per cent of the population has language represented primarily in the right hemisphere? There are a certain number of cases of 'crossed aphasia'; that is right-handers with language deficits after right-sided injury. It was evident even in the series examined by Abercrombie in the 1800s that there was a small percentage of people with right-hemisphere representation for language.

Data from anesthetizing one hemisphere

In more recent times we have also been able to determine the dominant hemisphere for language in uninjured brains. In a technique called the Wada test, an anesthetic called sodium amytal is injected into the artery leading to one side of the brain or the other. If the drug is delivered to the language side of the brain, a temporary paralysis of language function is experienced. The patient stands with both arms extended forward from the shoulders. Slowly the arm opposite the patient's 'language' hemisphere – usually the right arm – goes down as the brain areas of that opposite hemisphere that should be available for keeping it up are no longer operating. The patient cannot speak at all for several minutes and in the minutes after that, language sounds aphasic [. . .].

The results of this test confirm the statistics from incidence of aphasia after brain injury. Among right-handers with no history of early left-brain damage, approximately 95 per cent experience temporary interference with language after an injection of sodium amytal into the left carotid artery, which brings blood to the left hemisphere. Approximately 70 per cent of left-handers experience similar interference after left carotid injection. Of the remaining 30 per cent, half only have temporary paralysis of language function after right carotid injection. The other half would seem to have at least some degree of bilateral speech control (Hécaen and Albert 1978). The numbers for manual/visual languages may be a bit different. Some signers exhibit aphasic symptoms after left-hemisphere injection of sodium amytal (Damasio *et al.* 1986). However, there is some research suggesting greater right-hemisphere involvement in processing sign language (see Poizner, Klima and Bellugi 1987, for a review). The Wada test is used primarily as a method of determining which hemisphere is dominant for language in patients who must undergo brain surgery. The brains of these surgery patients, frequently epileptics for whom medications have not worked to control the epilepsy, while not acutely injured, by definition have some neurological problem. In neurologically normal populations, there would likely be even less indication of bilateral representation for speech/language.

Tachistoscopic presentation

It is also possible to present visual stimuli selectively to one hemisphere or the other in normal individuals in order to learn about which hemisphere is involved in processing them. When a person looks at a point, everything to the right of that point is in the right visual field. Everything to the left of that point is in the left visual field. Ordinarily, both eyes see both visual fields. However, information about the right visual field is sent by both eyes to the left hemisphere and information about the left visual field is sent by both eyes to the right hemisphere. [. . .]

The technique called tachistoscopic presentation allows normal subjects to react to a visual stimulus presented to only one visual field. The stimulus is flashed to one or the other side of the fixation point so briefly that the subjects do not have time to change their gaze, allowing the image to be part of the other visual field. In normal subjects the left and right visual areas of the brain communicate via the corpus callosum. This means that information will be processed regardless of the visual field in which it is presented. However, linguistic stimuli will be processed more quickly and more accurately when presented to the right visual field (left hemisphere). Such a pattern can be seen in tachistoscopic testing over a number of stimuli. While tachistoscopic presentation is not as accurate as brain damage in indicating which side of the brain is dominant for language (only between 60 per cent and 70 per cent of normals demonstrate a left-hemisphere dominance for language, for example, via tachistoscopic presentation, while from brain damage studies we know the numbers should be higher, closer to 97 per cent), the technique is certainly non-invasive, and thus substantial numbers of tachistoscopic studies have been conducted since the 1950s to determine which hemisphere is dominant for different aspects of language and non-language processing.

The dichotic listening technique

A second technique that has been developed to study lateral dominance in normal individuals is called *dichotic listening*. While tachistoscopic presentation uses visual stimuli, dichotic presentation uses auditory stimuli. This technique relies on the fact that the right ear has stronger connections to the left hemisphere than it does to the right (and conversely for the left ear). Thus information presented to the right ear, while it will be sent to both hemispheres' auditory centers, will be better processed contralaterally. Under normal circumstances, we see no effects of this curious organization, but when we 'overload the system', we can infer that one hemisphere or the other performs better for a given sort of stimulus type. For example, if normal subjects hear triads of different words presented simultaneously to both ears (the right ear might hear '2', '8', '5' while the left ear hears '9', '1', '6'), and [are] asked to repeat back everything they hear, most subjects are more likely to forget '1', the information that went to the left ear – that is, the right hemisphere – from the mid-point of the triad. Over a number of trials, we can see a consistent performance for language materials like these numbers that is the opposite of the pattern we see for non-verbal meaningful materials such as babies' cries, fire sirens, bird whistles, etc. This technique, then, complements tachistoscopic presentation in allowing us to evaluate lateral dominance for spoken language as well as written language. As with tachistoscopic presentation, it does not give us the same clarity that explicit brain damage does, but it is infinitely easier to manipulate.

Split-brain patients

Under normal circumstances, the two halves of the brain work in tandem. Sensory information travels along pathways from one side of the body to the opposite side of the brain. Acoustic stimuli arrive at the brain along both contralateral and ipsilateral pathways.

Visual information from each visual hemifield is sent to the opposite hemisphere [. . .]. In the normal human brain, all of this information is shared between the two hemispheres as signals are passed via the corpus callosum, the bundle of some 200 million nerve fibers connecting the left and right hemispheres. There is, however, a small but well-studied population of individuals in whom this inter-hemispheric communication is no longer possible. The same fibers which allow for the sharing of information between the two hemispheres unfortunately also allow for the electrical misfirings which result in a kind of intractable, epileptic seizure. In some cases the only way to allow the patient to live productively is to sever the main inter-hemispheric connections in a process called a commissurotomy. This procedure was developed in the 1940s and 1950s but its use declined as better drugs were developed for managing epilepsy. The everyday behavior of these 'split-brain' patients is essentially normal. Occasional eerie reports of dissociation of behavior of the left and right sides of the body are reported. Some patients report difficulty in learning new name–face connections. The right hemisphere seems to be particularly involved in interpreting visuo-spatial information, in this case, the appearance of the new face. The left hemisphere will process the new linguistic information: the name. It is not surprising that this particular kind of learning would be problematic after a commissurotomy. Beginning in the 1950s, many experiments were performed testing the linguistic abilities of the isolated left and right hemispheres in these patients.

One type of experiment has the split-brain patient sit at a table with a screen blocking the view of objects on the other side. If the patient reaches behind the screen with the left hand, tactile information about the object is conveyed only to the right hemisphere and the person will be unable to name the object held. Objects not seen, but held in the right hand are readily named. The isolated right hemisphere can process the tactile information. It can guide the left hand to choose a similar item from an array of items, but it cannot name the item. From such a study we can learn what language the isolated right hemisphere can process and how independent the isolated left hemisphere can be in processing language [. . .].

LOCALIZATION OF LANGUAGE WITHIN THE LEFT HEMISPHERE

The dominance of the left hemisphere for language for most people is largely uncontroversial. Determining the particular left hemisphere areas involved in the various aspects of language comprehension and production is more difficult.

History

The claim that linguistic ability is localized in a particular area of the left hemisphere is generally credited to the French neurologist Paul Broca. In 1861 (interestingly, four years before he noted that left- but not right-sided brain damage seemed to result in language disturbance) he presented data that implicated the area of the frontal lobe just in front of the Sylvian fissure in language function. In 1874, Carl Wernicke demonstrated that for two patients he had seen, damage to an area in back of the Sylvian fissure had caused linguistic deficits. The trends toward describing very specific left-hemisphere areas and ascribing specific language functions to these areas continued for some time. Henderson *et al.* (1992) quote a prominent professor of medicine, Ludwig Lichtheim, who wrote that once aphasiologists had determined the ways in which language functions were localized and interconnected in the brain, neurologists 'should then be able to determine the exact place of any discontinuity in these paths and account for its symptomatic manifestations with the same precision as we do for those of a motor or sensory paralysis depending on a lesion of the peripheral nerves' (Lichtheim 1885).

As Henderson [*et al.* explain], not all neurologists of the late nineteenth century were comfortable with this narrow delimitation of speech centers. Hughlings Jackson (1878) pointed out that 'to locate the damage which destroys speech and to locate speech are two different things'. Freud (1891) agreed with Jackson's skepticism in interpreting aphasiological data. For Freud, it seemed likely that there was only one type of aphasia. Different symptoms such as those found in Broca's vs. Wernicke's patients [. . .] were to be explained by the proximity of the patients' lesions to either motor or sensory areas in the left hemisphere.

Modern aphasiologists are still not entirely in agreement over the extent to which specific language functions are subserved by specific brain areas. [. . .] However, even the 'localizationists' of today have heeded the cautions of the past [. . .].

Cortical stimulation

One modern technique that is useful in determining which areas of the left hemisphere are involved in language processing is called *cortical stimulation*. Consider the maps one can make of left-hemisphere sites where electrical stimulation interferes with naming ability in hearing individuals.

In order to determine which cortical areas of the brain are involved in speech production in patients who need to have brain tissue removed because of intractable epilepsy, electrical stimulation of the brain surface is used to make a map of the patient's brain. The brain does not contain pain receptors so patients may remain conscious and attempt to name pictured items while electrical stimulation is being applied to different points in their brains (See Figure 4.1.1). If the stimulation is in an area of the brain normally involved in speech, it interferes with patients' ability to name; they may be totally unable to speak or unable only to name a simple picture of an object. Alternately, they may experience hesitation, slurring or repetition in attempts at naming the pictured object. This interference *never* follows the stimulation of parts of the non-language-dominant half of the patient's brain (Penfield and Roberts 1959).

It is of interest to consider the effects of cortical stimulation on a signed language. Haglund *et al.* (1993) tested a woman who had learned American Sign Language (ASL) as a child. Left-hemisphere stimulation affected both languages but some areas affected primarily ASL and other areas affected primarily English.

Imaging techniques

Only recently have imaging techniques such as CAT-scans (Computerized Axial Tomography), PET-scans (Positron Emission Tomography) and MRIs (Magnetic Resonance Imaging) offered precise information about lesion sites in living patients.

In these techniques, people's brains are 'x-rayed' and computer programs convert the pictures into maps we can recognize. CAT-scans are good at localizing many sorts of

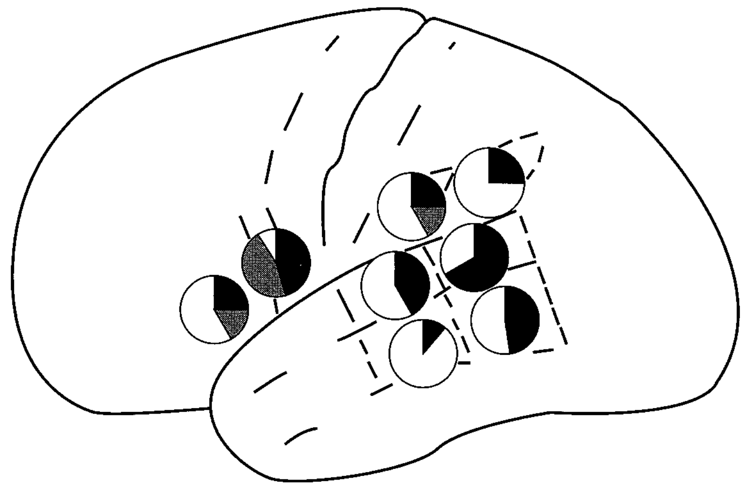

Figure 4.1.1 A cortical stimulation map [of the left hemisphere]. Filled areas of circles indicate the percentage of patients with anomia when stimulation is at that point. (Adapted from G. Ojemann, Brain organization for language from the perspective of electrical stimulation mapping, *Behavioral and Brain Science*, 1983, 6: 199.)

lesions, but not very recent ones or ones very close to the skull. MRI scans can demonstrate some of the lesions that CAT-scans cannot. PET-scans can provide ongoing pictures of the changes in brain activation over time (e.g. glucose uptake that occurs when an area of the brain needs oxygen for more strenuous activity), and thus could provide the best evidence of how language processing takes place dynamically. However the pictures PET-scans provide are much fuzzier than those of MRIs.

Currently many new imaging techniques are competing to provide crisp pictures of brain activities as they take place. One such solution is the evoked potential technique. This is used with normal subjects by attaching a number of electrodes on the scalp and then seeing which ones show electrical activity in the brain milliseconds after some stimulus has involved one or more areas of the brain that have thus emitted an electrical response. This technique is often abbreviated as ERP, standing for *event-related evoked potential*. The 'event' is the stimulus; the evoked potential is the electrical response in the brain that can be read through the scalp.

A second imaging technique of interest is the fMRI, *functional MRIs*; like cartoons they provide a series of snapshots of brain activity so quickly that we appear to see a continuous process unfold on the video screen. [. . .]

CONCLUSION

Even armed with precise information about lesion sites, we cannot escape the difficulty inherent in studying brain damage. Individual brain representation for language may vary. Lesions cannot be expected to damage only areas that functioned together before the brain damage. Also, investigators' views on normal language influence the structure of the tasks administered to their patients. Yet, in spite of these many difficulties, substantial progress has been made in creating a map of a general language area in the brain.

Converging evidence from studies of aphasia, sodium amytal injection, split-brain patients, and tachistoscopic and dichotic presentation points to left-hemisphere dominance for language organization and processing in most humans [. . .]. Aphasia lesions, cortical stimulation, and the brain-imaging techniques permit us to delimit a 'language area' within the left hemisphere around the Sylvian fissure.

NOW, THINK, DO!

4.1.1 As a way of gaining confidence in the main relationships between language use and the brain, draw a sketch of the left cerebral hemisphere and label the sylvian fissure, the central fissure, and the frontal, parietal, occipital and temporal lobes. Test yourself until you can do this from memory. Then, on the basis of library reading, make notes with arrows to parts of the diagram, indicating which areas are implicated in which aspects of language use.

FURTHER READING

For basic information and terminology on the brain refer to a medical dictionary, for instance Martin (2002). Look there too for a labelled diagram of the *cerebrum*. The BBC's online science website has a useful description of the brain. To prepare for understanding more advanced material, such as the surveys by Kutas, Van Petten and Kluender (2006) and Pulvermüller (2007), it would help to first go through the sections on language in a big book on neuropsychology or cognitive neuroscience. One such is Banich's book, which has excellent pictures and an interesting description (2004: 84–5) of what it is like to have one's brain activity recorded in an fMRI (functional magnetic resonance imaging) study.

REFERENCES

Banich, M.T. (2004) *Cognitive Neuroscience and Neuropsychology* (2nd edn). Boston: Houghton Mifflin.

BBC Science, at <www.bbc.co.uk/science/humanbody/body/factfiles/brain/brain.shtml>.

Bloomer, A., Griffiths, P. and Merrison, A.J. (2005) *Introducing Language in Use: a Coursebook*. Abingdon: Routledge.

Broca, P. (1861) Remarques sur le siège de la faculté du language articulé suivies d'une observation d'aphémie. *Bulletin de la Societe Anatomique* 6, 330.

Broca, P. (1865) Sur le siège de la faculté du language articulé. *Bulletin de la Societe d'Anthropologie* 6, 337–93.

Brown, J.W. and Chobor, K.L. (1992) Phrenological studies of aphasia before Broca: Broca's aphasia or Gall's aphasia? *Brain and Language* 43, 475–86.

Damasio, A., Bellugi, U., Damasio, H., Poizner, H. and Van Gilder, J. (1986) Sign language aphasia during left-hemisphere amytal injection. *Nature* 322, 363–5.

Forstl, H. (1991) The dilemma of localizing language: John Abercrombie's unexploited evidence. *Brain and Language* 40, 145–50.

Freud, S. (1891) *Zur Auffassung der Aphasien* (trans. into English, 1953, by E. Stengel, as *On Aphasia*). New York: International University Press.

Haglund, M., Ojemann, G., Lettich, E., Bellugi, U. and Corina, D. (1993) Dissociation of cortical and single unit activity in spoken and signed languages. *Brain and Language* 44, 19–27.

Hécaen, H. and Albert, M. (1978) *Human Neuropsychology*. New York: Wiley.

Henderson, V., Buckwalter, J., Sobel, E., Freed, D. and Diz, M. (1992) The agraphia of Alzheimer's disease. *Neurology* 42, 776–84.

Hughlings Jackson, J. (1878) On affectations of speech from disease of the brain. *Brain* 1, 304–30/*Brain* 2, 203–22, 323–56.

Kutas, M., Van Petten, C.K. and Kluender, R. (2006) Psycholinguistics electrified II (1994–2005), in M.J. Traxler and M.A. Gernsbacher (eds) *Handbook of Psycholinguistics* (2nd edn). Amsterdam: Elsevier, Ch. 17, 659–724.

Lichtheim, L. (1885) On aphasia. *Brain* 7, 433–84.

Martin, E.A. (2002) *Concise Colour Medical Dictionary* (3rd edn). Oxford: Oxford University Press.

Penfield, W. and Roberts, L. (1959) *Speech and Brain Mechanisms.* Princeton, NJ: Princeton University Press.

Poizner, H., Klima, E. and Bellugi, U. (1987) *What the Hands Reveal about the Brain.* Cambridge, MA: MIT Press.

Pulvermüller, F. (2007) Word processing in the brain as revealed by neurophysiological imaging, in M.G. Gaskell (ed.) *The Oxford Handbook of Psycholinguistics.* Oxford: Oxford University Press, Ch. 8, 118–39.

Wernicke, C. (1874) *Der aphasische Symptomencomplex.* Breslau: M. Cohn und Weigert.