CONSIDERATION OF THE PAST, PRESENT, AND FUTURE ROLES OF THE NEUROSCIENCES IN THE LINGUISTIC SCIENCES

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For thousands of years, the human brain has caused both bewilderment and fascination. And although the brain is the ultimate source, arbiter, and conduit of human language, an understanding of even the rudiments of its role in language comprehension and production has been a relatively recent development, arguably dating to the latter half of the nineteenth century. In the present discussion, a review of significant approaches to the human brain will be considered from a diachronic perspective. Particular emphasis will be placed upon developments which have provided the foundation for interaction between the neurosciences and linguistic sciences. Consideration of emerging approaches to the study of the brain will also be made for, it is maintained, such approaches will be particularly fruitful in providing new and important insights into the brain/language relationship.

0. Introduction: Our universe within

In his ambitiously compendious volume, How the Mind Works, Steven Pinker (1997:24) wryly notes that, while ‘the 1990s have been named the Decade of the Brain, ... there will never be a Decade of the Pancreas’. While the relative importance of the investigation of the brain versus the pancreas may be eminently obvious, Pinker’s observation actually belies a truism about the human brain. That is, unlike any other organ, the brain has what Pinker terms ‘special status’ which derives ‘from a special thing the brain does, which makes us see, think, feel, choose, and act. That special thing is information processing, or computation’ (1997:24).

Indeed, the brain’s computational ability is one of the reasons why the multifarious functions of this organ have been difficult to understand. Even gaining rudimentary insights into how the nervous system transforms simple sensory inputs into complex mental constructs has taken decades of research. For example, in the auditory system, a word to be perceived begins (simply) as a series of sound waves causing vibrations which impinge upon the tympanic membrane (eardrum) of the hearer. These vibrations are transduced, transformed, and relayed to higher centers of the brain where they are ultimately interpreted as a lexical unit (Rosenberg 1982; Lieberman & Blumstein 1988; Mack 1991). This unit has associated with it often rich denotative and connotative meanings, an understanding of the rules governing the syntactic and thematic roles to which it may be as-
signed, and specific acoustic cues enabling the listener to engage not only in speech recognition, but speaker recognition.

The human brain is remarkable not only computationally but structurally as can be demonstrated by an examination of the primary building block of the brain, the neuron (nerve cell). Although an adult brain weighs just three to four pounds, it contains a total of approximately one trillion cells, of which about 100 billion are neurons — nerve cells which transmit electrochemical signals throughout the peripheral and central nervous system (CNS). Neurons are generated at an average rate of about 250,000 per minute prior to birth (Cowan 1979), a fact which helps provide some perspective on the magnitude of the numbers of neurons in the developing brain. Moreover, neurons vary considerably in shape, size, and function (Fischbach 1992). The complexity of the human brain becomes especially apparent in view of the number of other neurons with which each neuron connects: Any given neuron may connect, via synapses, to approximately 1,000 other neurons, and each neuron may have thousands of synapses (Stevens 1979; Lamb 1998). In addition, the scale of the neural components of the brain is exceedingly small. For example, approximately 20,000 to 25,000 neurons occupy one cubic millimeter of cerebral cortex (Lamb 1998), and the width of the synaptic cleft — the juncture between neurons — is less than one ten-millionths of an inch. (The cortex, whose name is derived from the Latin word for plant bark, is the outer layer of the brain — a thin sheet of gray matter containing the nerve cell bodies.) Hence, gaining an understanding not only of individual neurons but of the functions of inter-related networks of neurons can be highly difficult due, in part, to the complexity of the brain's 'wiring system' and to the extremely small scale of the components involved.

In addition, as Francis Crick 1979 has aptly indicated, introspection about the brain is remarkably unrevealing. Indeed, he states that 'we are deceived at every level by our introspection' (1979: 132). For example, Crick 1979 and Crick & Koch 1992 note that most individuals do not realize that they have a 'blind spot' in each visual field caused by an absence of photoreceptors in a small area of the retina — that area in which the optic nerve projects to the brain. The blind spot is undetected because the brain interpolates the missing information. Moreover, one of the most anatomically striking features of the brain is a deep longitudinal fissure dividing the brain into a left and right hemisphere, each of which has specialized functions and preferred processing modes (Springer & Deutsch 1993). Further, each hemisphere subserves the functions of the body contralaterally (i.e., the right half of the brain controls the left side of the body and the left half of the brain controls the right side of the body). Thus the brain is bifurcated both anatomically and functionally. Yet, unless one obtains explicit information about the anatomical bifurcation and functional lateralization of the brain, an awareness of the fact that the brain has two discrete hemispheres remains entirely inaccessible to introspection or consciousness.

These relatively simple examples reveal why Crick (1979:132) concludes that 'our capacity for deceiving ourselves about the operation of our brain is almost limitless, mainly because what we can report is only a minute fraction of
what goes on in our head.' He adds that 'this is why much of philosophy has been barren for more than 2,000 years and is likely to remain so until philosophers learn to understand the language of information processing'. Although enormous strides in understanding the brain have been made since Crick wrote these words (and although it can be argued that philosophy has hardly been 'barren' for the past two millennia), it is the case that, throughout most of the history of *Homo Sapiens*, the role of the brain — our 'universe within' — has been variously misunderstood, misinterpreted, and even maligned.

### 1.0 Where is language? Historical perspectives

Archeological evidence has revealed that in many Old- and New-World prehistoric cultures a crude form of surgery, trepanation, was practiced relatively frequently. Trepanation, in which a hole is bored into the skull, was carried out possibly for ritualistic or medicinal purposes. What is remarkable about this is not only the frequency with which trepanation occurred (one wonders at the temerity of those who dared to carry out — and to undergo — the procedure!), but the fact that it had a fairly high survival rate. (This is revealed by signs of healing around the site on the skull.) Trepanation suggests that prehistoric societies possessed 'strong beliefs about the brain and behavior' (Finger 1994:5) since the procedure may have been used to treat headaches, seizures, and mental disturbances. However, this interpretation is mitigated by the observation that 'these disorders were likely to have been attributed to demons, and it is conceivable that the holes were made to provide the evil spirits with an easy way out' (Finger 1994:5). Thus there is no clear evidence that the 'trepaners' understood the function of the brain or why trepanation was efficacious, if indeed it was.

However, an ancient Egyptian text dealing with head injuries, the *Edwin Smith Surgical Papyrus* (parts of which date from at least 2000 B.C.), does reveal some insightful perspectives on the central nervous system. Finger (1994:8) says that early Egyptian physicians were aware that 'symptoms of central nervous system injuries could occur far from the locus of damage', suggesting a relatively advanced understanding of the relationship between the central and peripheral nervous systems. Yet in spite of their apparent insights into the physiology of these systems, the ancient Egyptians still that believed the heart, not the brain, was the paramount organ — an organ that recorded all of one's good and evil deeds. And, as evidence from mummification indicates, the heart was accorded higher status than the brain which, unlike the heart and other organs, was virtually never preserved.

Early written records of medical practices from other cultures also reveal some knowledge about the brain. For example, the ancient Indian work, the *Atharvaveda*, 'provides descriptions of epilepsy, insanity, neuralgia, headaches, and blindness' (Finger 1994:11) but again, the heart was viewed as more important than the head, as revealed in evidence from Vedic collections on medicine. The ancient Chinese also emphasized the primacy of the heart which they believed would cause memory lapses and insomnia if it were not filled with energy and blood.
Moreover, in words dating from well over two thousand years ago and attributed to or inspired by Hippocrates — long acknowledged as the father of modern medicine — these assertions are made:

It follows that southerly winds relax the brain and make it flabby, relaxing the blood-vessels at the same time. Northerly winds, on the other hand, solidify the healthy part of the brain while any morbid part is separated out and forms a fluid layer round the outside. ... The brain may be attacked both by phlegm and by bile and the two types of disorder which result may be distinguished thus: those whose madness results from phlegm are quiet and neither shout nor make a disturbance; those whose madness results from bile shout, play tricks and will not keep still but are always up to some mischief. ... Warming of the brain ... takes place when a plethora of blood finds its way to the brain and boils (Lloyd 1978:248-9).

Thus, the brain was not only believed to alternate in consistency (from ‘flabby’ to solid) due to atmospheric changes, but was deemed capable of housing a cauldron of boiling blood. It was also believed to cause insanity should it be attacked by two of the four ‘humors’ — one now known to be respiratory-system mucosa and the other an alkaline fluid secreted by the liver. On the other hand, Hippocrates and his followers accurately understood that the brain controlled the body, and they rejected the idea that gods and demons caused seizures (Finger 1994).

In spite of such insights, the ancient Greeks (as well as the ancient philosophers and linguists of India) fared better in their understanding of language than they did of the brain. For example, Aristotle’s Poetics, a commentary on literary theory dating from the third century B.C., provides an extensive and relatively sophisticated discussion of rhetoric, diction, stylistics, morphology, syntax, metaphor, grammatical gender, word coinage, and articulatory phonetics. Moreover, Aristotle clearly and often accurately defines such units as free and bound morphemes, syllables, and sentences. Yet at the same time he believed that the heart, not the brain, was the body’s nerve center and the seat of intelligence and that the function of the brain was to cool the blood (Adams 1971). (By contrast, Aristotle’s mentor, Plato, correctly identified the brain as the seat of the intellect [Longrigg 1998].)

Considerable advances in understanding the brain came with the 2nd-century Greek physician and anatomist, Galen, who actively practiced as a surgeon in Pergamon and later served as court physician to four Roman emperors. In his teachings, which prevailed for approximately 1,500 years, Galen correctly concluded that both motoric and sensory functions originated in the brain, and many of his theories provided the foundation for later work on the CNS. Further, he demonstrated a perspicacious understanding of the value of combining logos (reason) with experience in the healing arts (Walzer 1946). Nonetheless, his work still represented ‘a reservoir of medicine mixed with myth and magic’ (Fincher 1984:13), for Galen maintained that ‘vital spirits’ produced in the heart were
transformed into ‘animal spirits’ in the brain where they were stored in the ventricles until needed (Finger 1994).  

By the Middle Ages in Europe, most physicians still made erroneous assumptions about the structure and function of the brain. Although Medieval sketches of the brain depict the ventricles (cavities in the brain filled with cerebrospinal fluid), they were believed to be ‘a cluster of psychic cells charged with powers of memoria, imaginativa, cogitativa and sensus communis’ (Fincher 1984: 11). However, in 1543, Andreas Vesalius of Brussels published De humani corporis fabrica, a goldmine of anatomical illustrations and woodcuts (some possibly by Titian or the school of Titian) depicting the brain and body (Tarshis 1969). Most significantly, the central nervous system was, at last, portrayed and described relatively accurately, and Vesalius’ book revealed detailed knowledge of the structure of the brain, the spinal cord, and even the cranio-facial nerves (Lind 1949).

Finally Descartes, one of the founders of the Enlightenment, refers to the functions of the central nervous system in his 1664 work, Description du corps humain. His views reflect a synthesis of philosophy, religion, physiology, and neuroanatomy, as is revealed in the following description of his beliefs about the soul and cognition (Carter 1983:138):

In order to act reasonably [Descartes believed that] the soul must act through the agency of some part of the body, ... In order to will, the soul acts on the pineal gland, so that it pushes the surrounding spirits, ... which then mechanically control the body’s movements in such a way that the soul can consequently perceive the objects of its volition. ... Ideas are corporeal impressions caused by configurations of individual impressions made by spirits issuing from similar configurations of nerve endings in ventricle III, the middle ventricle of the brain.

In truth, in light of the complexity of the human brain (or, in fact, of the central nervous system which includes the brain and spinal cord), it is not surprising that a relative lack of understanding endured for thousands of years about its structure and function. And although some microscopic views of nerve tissues were made in the Netherlands by Anton van Leeuwenhoek and in Italy by Marcello Malphighi as early as the 17th century, it has been little more than one hundred years since Camillo Golgi devised a method for selectively staining nerve tissue so that individual neurons could be viewed microscopically and in great detail (Hubel 1979). And it was not until the 19th century that differential FUNCTIONS of brain regions — particularly as they related to language — were fairly well understood. It is thus understandable that early physicians, anatomists, and philosophers knew relatively little about the brain’s neural architecture, its physiology, or its role in acquiring, perceiving, and producing language.

What is also relevant to the present discussion is that, from the time of the ancients to the mid-19th century, those interested in understanding the brain and those interested in understanding language had relatively little substantive information to provide one another. Arguably, it was not until physicians undertook
systematic observations of aphasia (language impairment due to specific types of brain damage) that meaningful insights about the brain-language relationship began to emerge.

One early commentary on aphasic-like symptoms was made by a French physician, Lordat, and appeared in the 1843 *Journal de la société de médecine-pratique de Montpellier* (excerpted in Paradis 1983). In this commentary, Lordat writes of an apparently aphasic patient who had lost all language functions, save the ability to use swear words one of which, according to Lordat, was 'the most energetic swear-word in our language, ... which our dictionaries have never dared to print' (Paradis 1983:4). Lordat also assumed that the patient was unaware of the meaning of what he was saying since the man was both intelligent and a priest. It is unlikely that either intelligence or religious persuasion correlates with type of language loss in aphasia, but Lordat's observations about the linguistic abilities of his 'apoplectic' patient presaged thousands of subsequent studies — clinical, psycholinguistic, and neurolinguistic — of the relationship between brain damage and the use of language.

Specifically, serious neurological study which had a profound impact upon the linguistic sciences emerged in the late 19th century when a French physician, Paul Broca, observed that a specific region of the left frontal lobe (now known as Broca's area) was apparently responsible for certain types of speech production. This area has been implicated in non-fluent and agrammatic speech and in some language-processing deficits (now recognized as 'Broca's aphasia'). And in the 1890s, a German physician, Carl Wernicke, provided further information regarding the relationship of brain structure to language behavior when he observed another form of aphasia — one largely characterized by fluent but meaningless speech and usually resulting from damage to the temporo-parietal region of the left hemisphere. This is termed 'Wernicke's aphasia'.

The importance of the study of aphasia in the linguistic sciences cannot be overestimated. As will be indicated below, investigations of aphasia were largely responsible for the emergence of several major research foci which, by the mid-20th century, dominated much of the work that furthered an understanding of the brain/language relationship.

2.0 Language is found: Major trends in the mid-20th century, 1950-1980

Anecdotal evidence suggests that some linguists look back wistfully upon the 1950s through the 1970s as a 'golden era' in the linguistic sciences. However, this 'golden era' may have had a major competitor. As Greene maintains (1974:497,499),

The events of the very late eighteenth century and the early nineteenth century [are ones] which all linguists seem to recognize as revolutionary, formative, and "paradigmatic" in the sense defined by Thomas Kuhn in his book *The Structure of Scientific Revolutions*. ... With respect to the situation in linguistics since about 1870, there seems to be general agreement that there have been revolutionary de-
velopments, though not of a kind that can be fitted into Kuhn’s model of anomaly, crisis, and paradigm substitution. What has taken place is not a revolution within the framework of historically oriented comparative philology but rather a dramatic shift of interest and attention from diachronic to synchronic studies.

Yet even if a full-fledged Kuhnian revolution did not occur in linguistics in the 20th century, there was a relative explosion of linguistic study in numerous areas of language inquiry during this time. For example, Newmeyer 1980 notes that, while official membership in the Linguistic Society of America stood at 829 in 1950, it rose to 4,166 by 1968. And while only sixteen doctorates in linguistics were awarded in the United States in 1956-57, 177 were awarded in 1972-73. While this was still a small percentage (.51%) of all doctorates awarded in 1972-73, it did represent an elevenfold increase over a sixteen-year period. (During the same period, the number of doctorates awarded in all fields increased only fourfold.)

It is tempting to date the onset of widespread interest in linguistics, at least in the U.S., to the appearance of Noam Chomsky’s 1957 seminal work, Syntactic Structures. Here he presents his theory of transformational-generative grammar — a rationalist approach to the study of language diametrically opposed to that of, for example, the empirical behaviorist approach of B.F. Skinner (whose volume, Verbal Behavior, appeared in the same year). Indeed, by the time Chomsky’s next major work, Aspects of the Theory of Syntax, was published in 1965, linguistics graduate students were already fervidly memorizing transformations, drawing often-complex inverted tree diagrams, and ardently debating about the psychological reality of deep structures.

Meanwhile, fresh ideas were emerging (or had recently emerged) from numerous fields within linguistics as evidenced by a sampling of works which are now standards. These included volumes on phonetics and phonology (Jakobson & Halle 1956; Chomsky & Halle 1968); sociolinguistics and dialectology (Hymes 1964; Labov 1966); historical linguistics (Robins 1967); psycholinguistics (Whorf 1956; Brown 1970); child-language acquisition (Smith & Miller 1966); bilingualism and second-language acquisition (Weinreich 1953; Albert & Obler 1978); language universals (Greenberg 1966); the philosophy of language (Searle 1969); the origins of language (Lieberman 1975); animal communication (Seebock 1977); and neurolinguistics (Lennieber 1965; Whitaker & Whitaker 1977).

The neurosciences informed (if sometimes only tangentially) research in virtually all of the above areas. But it is here maintained that in the mid-20th century the neurosciences had their greatest impact upon three major topics of inquiry, all of which fell under the rubric of neurolinguistics. These included (1) the use of insights gleaned from the study of brain-damaged individuals, particularly those with aphasia; (2) the view of language as anatomically localized and functionally discrete; and (3) a belief in the pre-eminent status of the left cerebral hemisphere as the ‘control center’ for language.
2.1. Brain damage: A window on the brain

Brain damage has long been one of the primary sources of information about the organization of language in the brain, and myriad types of language impairment resulting from brain damage have been documented. These include, but are not limited to, agraphia (impairment in writing with possible preservation of the ability to read), alexia (impairment in reading with possible preservation of the ability to write), anomia (impairment in the retrieval of lexical items from memory), aprosody (impairment in the ability to use suprasegmentals), and aphasia (impairment in the production and/or perception of language manifested, e.g., selectively or primarily as mild to severe difficulties in the comprehension and production of morphosyntax, as in Broca’s aphasia, or as mild to severe difficulties in the comprehension and production of semantically meaningful speech, as in Wernicke’s aphasia).

There are, of course, problems with extrapolating about intact brains using information based upon damaged brains — an approach known as ‘deficit analysis’ (e.g., Gazzaniga 1984; Caplan 1987). To determine the locus of damage, examine its behavioral consequences, and then infer that the locus involved is responsible for the lost or impaired abilities reflected in the behavior overlooks several widely accepted facts. First, damage to a particular region of the brain does not produce identical results in all individuals. Second, various sites of damage in different individuals may yield strikingly similar impairments. Third, brain-damaged patients may employ compensatory strategies that can mask the severity of their problems. And fourth, establishing a correlation between the site of neurological damage and a behavioral deficit is often based upon the assumption that the lesion is in the region that subserves the previously normal behavior when, in fact, the damage has caused a disruption in the neural connections which implement the behavior.

A simple analogy is the following: Cutting the cable connecting a computer to its monitor results in an immediate loss of the visual display (assuming that the computer is on). If one only observed the site of damage (the ‘lesion’ in the cable) he/she might conclude that the visual display resided in or originated from the cable which, of course, it does not; it is merely the conduit for information stored at some distance from it. Of course, neurologists are far more informed about the functions of the brain (and most people know far more about computers) than this analogy might imply. Still, there is a long tradition of using the ‘lesion method’ (Banich 1997) and deficit analysis to correlate neurological damage with specific behaviors, and such an approach is still providing new information and insights (e.g., Saffran forthcoming).

Of all language disorders, aphasia has attracted the greatest interest among linguists not only due to the relatively high frequency with which it occurs — often as a result of a cerebral-vascular accident (stroke) — but because of its potentially devastating behavioral consequences. (For example, global aphasia can render an individual essentially completely unable to understand or produce language.) In addition, because the locus of brain damage can often be determined, at least generally, neuroscientists and aphasiologists have used aphasia as a
‘window on the brain’ — a window which can reveal at least some aspects of the relationship between brain regions and language functions.

The prolific polymath, Roman Jakobson, may be credited with emphasizing very strongly how insights from neurology — through the application of the lesion method in the study of aphasia — could inform linguistic theory (e.g., Jakobson & Halle 1956; Jakobson 1971). He asserts, however, that ‘the neurobiologist Hughlings Jackson (1835-1911) was the first to discern with insistence the linguistic aspect of aphasia’ (1973:59). Still, Jakobson’s primacy in advocating the potential value of interaction between the neurosciences and linguistics cannot be ignored. For example, one of the chapters in the book he co-authored with Morris Halle in 1956, *Fundamentals of Language*, is entitled, ‘Aphasia as a Linguistic Problem’ [emphasis added]. In this chapter, he decries the current state of affairs in aphasiology, stating that linguists are ‘responsible for the delay in undertaking a joint inquiry into aphasia’ in spite of the fact that ‘the aphasic disintegration of the verbal pattern may provide the linguist with new insights into the general laws of language’ (1956:56). In other words, even by the 1950s, the neurological data were bountiful, but few linguists were helping with the harvest.

In all fairness, as the aphasiologist Ruth Lesser 1978 points out, it was not merely a stubborn resistance to acquiring information from the neurosciences that impeded cross-disciplinary interaction in aphasiology in the mid-20th century. Lesser (1978:ix) observes that aphasiology ‘includes within its sphere some rich complexities, notably the physiology of the human brain, the psychology of the individual, and linguistic science’, which complexities may (understandably) have induced some individuals in potentially relevant disciplines to ‘shy away’ from the topic. And, from a more applied perspective, she notes that — at least as of the 1970s — the examination of aphasic patients was often ‘undertaken heuristically within a medical [not linguistic] tradition which emphasize[d] physical improvement, diagnostic labeling and the perpetuation of simplistic formulae for language disorders’.

However, even by the time Lesser penned the above comments, a sea-change was apparent: Jakobson 1971 notes that, as early as the 1940s, both A.R. Luria and Kurt Goldstein had attempted to apply principles of linguistic analysis to aphasia. And, by the 1960s, Jakobson and other linguists were relating types of aphasia to specific linguistic deficits, an approach later reflected in what would become one of the most widely administered aphasia test batteries ever used, the *Boston Diagnostic Aphasia Examination* (Goodglass & Kaplan 1983). This change was also evident in the scores of studies on aphasia conducted by linguists in the 1970s. One prominent linguist, Sheila Blumstein, contributed to many of these (e.g., Blumstein 1973; Blumstein, Baker, & Goodglass 1977; Blumstein et al. 1977) and is still doing so today (Blumstein, et al. 1991; Blumstein 1997). Another well-known linguist, Michel Paradis, also stimulated interaction between neurology and linguistics with the appearance in 1977 of his extensive survey and analysis of bi- and multilingual aphasies, and his work in this area has continued unabated. In addition, examination of the contents of major journals dealing with studies of the brain and language reveals that, by the 1970s, hundreds of
cross-disciplinary studies in the neurosciences and linguistic sciences were being undertaken in the U.S. and abroad — many of these on the subject of aphasia.

Thus the mid-20th century witnessed the application of insights from the neurosciences to the investigation of language breakdown and, more specifically, to aphasia. Concurrent with this was a dramatic increase of interest in the extent to which language was localized in the brain.

2.2. A locationist view of language

Due to insights gleaned largely from the study of aphasia, a still-pervasive view of language organization (long ago articulated by Wernicke) is that language is situated in ‘anatomically discrete [but] interconnected centers’ (Zurif & Swinney 1994:1056). It can be argued that such an approach had its roots in the work of the 18th-century anatomist, Franz Joseph Gall, whose work revealed a strongly locationist interpretation of brain functions. This is evidenced in the ‘pseudoscience’ he practiced — phrenology — in which the contours of the skull were correlated with aptitudes, abilities, and personality traits. While phrenology has understandably fallen into disrepute, Gall’s notions about locationism actually presaged the direction and research foci of much of the ‘real’ brain science that followed.

In the 1960s and 1970s, the locationist view found one of its strongest voices in the work of the neurologist Norman Geschwind (e.g., Geschwind 1979; Geschwind & Galaburda 1985a, 1985b, 1985c). Geschwind not only delineated regions of the cortex by function, but described pathways taken in the execution of certain language-related behaviors. For example, he states (1979:111) that ‘lesions in the angular gyrus have the effect of disconnecting the systems involved in auditory language and written language.’ He also asserts that

in [Wernicke’s] model the underlying structure of an utterance arises in Wernicke’s area. It is then transferred through the arcuate fasciculus to Broca’s area, where it evokes a detailed and coordinated program for vocalization. The program is passed on to the adjacent face area of the motor cortex, which activates the appropriate muscles of the mouth, the lips, the tongue, the larynx and so on.

Geschwind’s position, then, was that linguistic behaviors are anatomically and functionally localized and that cortical regions subserving language are connected to one another in highly specifiable ways. Some qualification is required however. According to Geschwind (1979:112), although ‘the partitioning of linguistic functions among several sites in the cortex is ... supported by much evidence, the rigidity of these assignments should not be overemphasized’. A related point is made by Banich (1997:53) who notes that a locationist interpretation may be more appropriate for certain cognitive functions, such as language, than for others, such as ‘certain aspects of memory’ which may be more diffusely represented. Still, the belief that language is anatomically localizable has been a powerful one, and it pervaded much of the research in neurolinguistics in the mid-20th century.
For example, a locationist approach is evident in the early work of Penfield and Roberts 1959 who used electrocortical stimulation — the application of low-voltage currents to the cortex via electrodes placed on its surface during neurosurgery — to induce transient aphasic arrest. (During many neurosurgical procedures, the patient is awake, facilitating the assessment of linguistic functions intraoperatively; however there are newer variants of this procedure which permit electrocorticographic analysis post-operatively [Ojemann 1994].) With this procedure, Penfield and Roberts mapped the cortices of approximately 200 patients. Results revealed well-defined cortical regions that yielded aphasic arrest, usually in response to stimulation in the left hemisphere. These regions were the posterior portion of the third frontal convolution, a larger region in the posterior temporal and inferior parietal lobe, and an area in the mid-saggital fissure, which Penfield and Roberts characterized as Broca’s, Wernicke’s and the supplementary speech areas, respectively.

In 1978, Ojemann and Whitaker utilized electrocortical stimulation to map the language areas of two bilingual patients. Their comments, and of course the procedure they used, clearly reflected a locationist view of the brain. They state (1978:409) that ‘in most people, the cortical language zones include portions of the left hemisphere surrounding the Sylvian fissure, particularly the posterior inferior frontal lobe and posterior temporal lobe’. However, they also note that the precise extent in any one individual to which specific brain areas are involved in language remains a matter of controversy. Nonetheless, a major and still oft-cited finding in this study bears mention: Although Ojemann and Whitaker’s patients had different language backgrounds and neurological pathologies, they exhibited similar patterns of language organization as exhibited in their performance on naming tasks in their two languages during electrocortical stimulation. That is, in both patients, naming in the second language was impaired over a wider area of cortex than was naming in the first. Ojemann and Whitaker interpreted this as evidence of more diffuse representation of the second than of the first language.

The belief that language functions, and indeed specific languages, can be associated with certain brain regions was a pervasive one, and it still finds compelling support from clinical evidence. This is dramatically demonstrated in the performance of an aphasic patient (DL) examined over a course of years by the present author. This patient had, as a consequence of a stroke, undergone left-hemisphere damage and had right-sided paralysis (hemiplegia). He exhibited Broca’s-like symptoms primarily manifested as non-fluent agrammatic speech. Below are samples of his writing (Figure 1) and drawing (Figure 2) produced years after the onset of his aphasia and after extensive language therapy. (Prior to his stroke, DL had been a noted architect and had been an artist by avocation.)
Figure 1: Attempts by DL, at approximately twelve years after the onset of aphasia, to write the words cube, Florida, Molly, and Mack, dictated to him by the present author. He had considerable trouble writing the words so the author assisted by spelling them aloud. Note that DL's first attempt to write the letter <d> was <r>. Perhaps revealingly, these letters are acoustically similar when pronounced. (Both represent liquids). And, in response to hearing the sound of the letter <m> when Mack was spelled to him, DL wrote <E>, presumably reflecting the initial vowel sound when the letter <m> is pronounced. (This was just after he had successfully written the <M> in Molly, and reveals an inconsistency typical of much of his performance.) Since DL was right-handed and had right hemiplegia, he had to use his left hand for all manual tasks.

Evidence of the often remarkable specificity of functional impairments subsequent to brain damage (as graphically demonstrated in the figures above) no doubt contributed, particularly in the 1970s, to growing interest in the neurosciences and linguistic sciences in the laterality of functions in the human brain (see, e.g., Geschwind 1979). In fact, one could easily argue that at least several of the dominant research paradigms of the period from 1950 to 1980 involving the brain/language relationship were devoted to the study of cerebral laterality. Accompanying the increase in attention to laterality was an emphasis on left-hemisphere specialization for language.
Figure 2: A watercolor depicting a pastoral scene with a covered bridge, painted by DL after the onset of aphasia. According to reports by his wife, such paintings required hours of laborious effort, in part because they had to be rendered with his non-dominant hand. The contrast between DL's orthographic/linguistic and artistic abilities is quite obvious and strongly suggests differential localization of function for the abilities involved.

2.3. Language and the 'left brain'

Although the cause of the evolutionary development of cerebral dominance for language remains disputed (MacNeilage et al. 1993; Provins 1997; Lieberman 1998), clinical evidence has revealed that, for most right-handed individuals (about 95%), the left hemisphere subserves major language functions. It also does so for most left-handed individuals, although with a slightly smaller frequently (about 70%). In fact, for many years, the left hemisphere was termed the ‘dominant’ hemisphere while the right hemisphere was believed to play a negligible or ancillary role in language. (In fact, Penfield [1965] refers to the right hemisphere as the ‘uncommitted cortex’.)

Even into the 1980s, Geschwind was ardently discussing the brain from a perspective in which the left hemisphere was deemed solely or largely responsible for language (e.g., Geschwind and Galaburda 1985a,b,c). Moreover, the now-common use of the term, ‘left brain/right brain’ belies a belief that the cranium houses two distinct brains, and it reflects a popularized interpretation of laterality (e.g., ‘Are you a left-brained or a right-brained person?’). In truth, the left-brain/right-brain dichotomy over-simplifies the extent to which the two hemi-
spheres interact during language processing and other cognitive functions; it ignores the fact that under certain conditions the right hemisphere can exhibit a ‘left-hemisphere’ processing mode (Trope et al. 1992); and it underestimates the role of the right hemisphere in language use (Code 1997).

Nonetheless, the view that the two halves of the brain possess different capabilities (the left hemisphere being specialized for analytic and sequential processing and the right hemisphere for holistic and parallel processing, for example) has been captivating and abiding. (See Springer & Deutsch 1993 for an excellent overview.) It is also one that, especially prior to the 1990s, received substantial attention and support from neurologists and linguists as revealed by some of the prominent research paradigms applied to the study of cerebral functions.

In terms of assessing laterality and its relationship to the organization of language, the queen of all tests was, in the 1960s and 1970s, a non-invasive technique developed by Doreen Kimura called dichotic listening. This technique proved extremely popular because it was non-invasive and could be used in an experimental rather than clinical setting (and, perhaps to its detriment, by linguists with little or no training in neurology). Through the simultaneous presentation of competing stimuli to either ear — such as the presentation of the word one to the right ear and the presentation of nine to the left — it was believed that dichotic listening and its visual counterpart, the tachistoscopic presentation of stimuli to the left and right visual hemisfields (Caplan, et al. 1974; Soares & Grosjean 1981), could reveal the extent to which various types of stimuli were subserved by the right or left hemisphere.

Specifically, Kimura (1961, 1967) found that among patients with left- or right-temporal-lobe damage, as well as among normal subjects, stimuli presented to the right ear were generally reported more accurately than those presented to the left. This finding emerged if the stimuli had certain acoustic properties and the magnitude of the effect was related to the types of linguistic stimuli used. For example, stop consonants were found to yield a fairly strong right-ear advantage (Blumstein et al. 1975), while some types of musical sounds resulted in a left-ear advantage (Kimura 1964; Gordon 1980), and vowels produced a weak or unreliable ear advantage (Blumstein et al. 1975). Kimura and scores of others who administered dichotic-listening tests thus concluded that this technique provided an excellent method for determining not only which hemisphere was dominant for language, but to what extent, under what testing conditions and task demands, and with what types of stimuli and subjects (e.g., Van Lancker & Fromkin 1978; Springer & Searleman 1978).

Not surprisingly, the dichotic listening test grew rapidly in popularity and application (see the extensive review by Berlin & McNeil 1976) and continued to be used even to test the now-refuted hypothesis that language is lateralized differently in monolinguals and bilinguals (e.g., Albert & Obler 1978; Vaid & Lambert 1979). However, as Zatorre 1989 indicates, some dichotic tests lacked methodological rigor and their results may have been unreliable or invalid. For example, what appear to be laterality effects may, in some cases, be nothing more than
a reflection of attentional bias favoring one or the other ear (Bryden et al. 1983). Thus, in recent years, this approach has been used less extensively than it was its heyday of the 1970s (see however Bruder 1991; Yund et al. 1999) and is now rarely interpreted as providing an unambiguous view of cerebral laterality.

Another non-invasive approach, the measurement of brain waves as detected by electrodes placed on the scalp, was also applied to the study of cerebral laterality (e.g., Donchin et al. 1977; Molfese 1978; Molfese & Schmidt 1983). One application of this method, the electroencephalogram (EEG), was used to measure alpha wave activity — low-frequency waves whose amplitude is inversely correlated with activity. Thus, the more activation, the less the alpha-wave activity. With this approach, researchers concluded that the left hemisphere was more highly activated than the right during verbal tasks (Galin & Ornstein 1972). It is important to note that, in later years, substantial improvements were made upon this method, primarily involving the repeated presentation of similar stimuli so that averaging techniques could be utilized, as is done in a procedure using event-related potentials (ERPs). The ERP maps ‘regularities in external stimuli or events onto the regularities in brain activity time-locked to those events’, and these regularities ‘are mirrored, in part, in the modulations of electrical activity’ displayed visually as waveforms (Kutas & Van Petten 1994:83). Although, as Garnsey 1993 notes, not all of the processing that takes place in the brain is observable in ERP waveforms, ERPs are still used by some researchers in evaluating hemispheric effects (Kutas, Hillyard, & Gazzaniga 1988; Neville et al. 1997), and they remain a valuable source of information about how the brain deals with linguistic information (e.g., Kounias & Holcomb 1994; Kutas & Van Petten 1994; Gevins 1998).

Concurrent with the emergence, in the mid-20th century, of the dichotic-listening technique and the measurement of brain-wave activity was a neurological procedure, the Wada test. This test provided particularly strong support for the belief that the left hemisphere was dominant for language (Wada 1949; Wada & Rasmussen 1958). In this procedure, a barbiturate (sodium amytal) is injected into the carotid artery prior to neurosurgery in order to determine to what extent the left (or right) hemisphere subserves language. Injection of the drug into the artery results in a temporary anesthetizing of the hemisphere ipsilateral to the artery. If the anesthetized hemisphere controls language, the patient becomes temporarily mute. This test, which generally yields robust effects, served as a major source of data regarding the relationship of handedness to the lateralization of language (at least in the spoken mode) and it is still in use (Berthier et al. 1990; Ravdin et al. 1997; Wada 1997).

The mid-20th century also witnessed the application of another medical procedure that permitted researchers to investigate cerebral laterality (Sperry et al. 1969; Levy et al. 1972; Sperry 1974, 1982). That is, neurologists, psychologists, and linguists examined the behavior of commissurotomized or ‘split-brain’ patients — patients who had had part or all of the corpus callosum (and in some cases other commissures) severed to alleviate intractable epileptic seizures. (The corpus callosum is a major tract of millions of nerve fibers connecting the cortices...
of the two hemispheres.) This procedure yielded highly informative results about the specialized functions of the two hemispheres since it effectively prevents the hemispheres from communicating with one another via the cortex. For example, a commissurotomized patient might be unable to name an object, placed out of view, which he/she is palpating with the left hand: The sensory information is relayed to the right hemisphere subcortically but cannot be transmitted via cortical connections to the left hemisphere for production as a spoken word. Nonetheless, the patient knows what the object is, as can be demonstrated if he/she is asked to draw it. Split-brain patients thus revealed the extent to which language is subserved by the left hemisphere and provided valuable information about the linguistic abilities of the disconnected hemispheres. Indeed, although the right hemisphere has at least some linguistic abilities (e.g., Zaidel 1978; Kutas et al. 1988; Hutner & Liederman 1991), the behavior of commissurotomized patients revealed significant left-hemisphere dominance for most language functions. It also demonstrated that the two hemispheres subserve different albeit highly complementary functions — an observation supported by a considerable body of subsequent research (e.g., Code 1997; Vargha-Khadem et al. 1997; Karbe et al. 1998; Kurowski et al. 1998).

If one could imagine a technique particularly well suited for providing information about the differential functions of each hemisphere, it would perhaps involve the absence of part or all of one half of the brain. Indeed, since the 1970s, such situations have been the topic of considerable interest and research and have appeared as a consequence of a surgical procedure, a hemispherectomy, in which much or all of one hemisphere is removed. (Removal only of the cortex is called 'hemidecortication', although many researchers apply the term 'hemispherectomy' to the removal of the cortex or to the removal of a much more substantial portion of one hemisphere.) A procedure as radical as this is only undertaken in cases of severe brain pathology or damage, as for example, in Sturge-Weber-Dimitri syndrome (Dennis & Whitaker 1977) or Rasmussen encephalitis (Stark et al. 1995; Caplan et al, 1996). These and certain other neurological disorders may cause intractable epileptic seizures for which hemispherectomy may be the only means of obtaining partial or complete relief. In the 1970s, reports of patients (usually children) who had undergone such procedures generated particular interest because they provided relatively direct evidence of the capabilities not only of the disconnected hemispheres, as with ‘split-brain patients’, but of the capabilities of entirely isolated cortices or hemispheres. For example, Dennis & Whitaker (1977:102-3) observed that, of the three children whom they examined, the two who had undergone removal of the left hemisphere exhibited ‘difficulty in utilizing the syntactic information conveyed by words like when, after, and before, and in analyzing examples of overt instrumentals, ... especially those in which the surface word order was not the same as the temporal order of the action’. By contrast they found that ‘the isolated right hemisphere appear[ed] to acquire certain components of auditory language less well, especially the ability to respond to the structural or syntactic aspects of heard utterances’.
However, as compelling as these results were (and continue to be), inferences about normal brains (and hemispheres) based on hemispherectomy patients must be made with care. That is, hemispherectomies are undertaken only in cases of severe brain pathology so, prior to surgery, certain functions otherwise subserved by the impaired hemisphere may have been reallocated to the intact hemisphere. In addition, brain pathology is not always confined to one hemisphere or, subsequent to the removal of a hemisphere, there may be a shift of the remaining hemisphere over the midline and a concomitant enlargement of the lateral ventricle (Strauss & Verity 1983:2). Finally, removal of one hemisphere may result in the amelioration of presurgical glucose hypometabolism (Caplan et al. 1996) or in the disinhibition of functions in the remaining hemisphere. In any of these situations, post-operative behavior may not accurately reflect the abilities of a normal hemisphere in an intact brain.

In sum, the mid-20th century was an era rich with hypotheses about and methods for analyzing brain structure and function. And, by the beginning of the 1980s, work in the neurosciences had provided fertile ground for the emergence of fresh perspectives and new research paradigms relevant to the future of the linguistic sciences.

3.0 Back to the future: Recent and emerging developments

Nearly thirty years ago, Noam Chomsky (1972:1) commented about interdisciplinary efforts involving linguistics when he observed that there were signs ‘that the rather artificial separation of disciplines may be coming to an end. It is no longer a point of honor for each to demonstrate its absolute independence of the others’. He also said that ‘there is more of a healthy ferment in ... the particular branch of cognitive psychology known as linguistics ... than there has been for many years’. Chomsky’s observations may have been somewhat premature (see, e.g., Mack 1990), but they are now applicable to the blossoming relationship between the neurosciences and linguistic sciences. (This is not to overlook productive interdisciplinary work by linguists in other areas — for example, by those who have applied theoretical models from linguistics and cognitive science to the study of second-language acquisition [e.g., Flynn 1987; White 1990] or those who have used neurological constructs to inform language pedagogy [Danesi 1988]. However, discussion of such work is beyond the scope of the present paper.)

That is, concurrent with a virtual explosion of information about the human brain in recent decades, there has been a marked increase in inter- and multidisciplinary initiatives involving inquiries into the brain and language. One example of this was a weekly seminar held in the spring of 1998 at the University of Illinois under the auspices of the University’s Center for Advanced Study. Entitled ‘Mind, Brain, and Language’, this seminar was designed to explore ways in which the neurosciences (and the behavioral sciences) could inform theory and research in the linguistic sciences — and vice versa. Students and faculty from twelve academic units engaged in an exchange of information on selected topics from language evolution and child-language acquisition to computational modeling and
brain-imaging techniques. The culmination of this endeavor was a major conference devoted to the topic of mind, brain, and language. These initiatives, and others occurring worldwide, reveal a growing recognition of the fact that much of the 'cutting-edge' work in the neurosciences and linguistic sciences is now occurring at the interstices of once-insular (and insulating) disciplines.

It is therefore of interest to consider those areas in the neurosciences that are currently proving particularly rewarding in terms of informing the linguistic sciences and which, in so doing, are blurring or even erasing the lines between traditionally defined academic disciplines. These include the following topics and approaches: biologically based maturational effects upon language acquisition, the modularity of language, brain-imaging techniques, and the bilingual brain.

A. Youth is not wasted on the young: Biologically-based maturational effects on language acquisition

While individual differences in the structure and function of the brain have long been recognized, the systematic study of such differences has been particularly vibrant since the early 1980s. (See, e.g., Hartlage & Telzrow 1985.) Dean (1985:9) describes this work as follows:

The study of individual differences with its foundation in biology is concerned more directly with 'naturally' occurring variation in behavior and brain function than differences observed through manipulation of the examination of neuropathology. ... The objective ... is the portrayal of variation in brain function that can more heuristically be attributed to an interaction of genetic and environmental factors.

Indeed, in recent years, researchers have explored individual differences in work dealing with the effect of genetic and environmental factors on behavior. For example, some researchers have examined handedness (Gur & Gur 1980; Herron 1980; Witelson 1980; Basso et al. 1990; Murphy & Peters 1994; Driesen & Raz 1995), while others have investigated gender (Wittig & Peterson 1979; McGlone 1980; Kimura 1983; Pizzamiglio et al. 1985; Habib et al. 1991; Shaywitz et al. 1995; Witelson et al. 1995). Results of such studies have revealed interesting and sometimes controversial findings about the brain/behavior relationship and about the possible effects of genetic versus environmental variables.

Yet one type of individual difference that has generated an enormous amount of attention is age or, more specifically, the relationship between brain maturation and language acquisition. Many researchers have explored this relationship by testing the critical-period hypothesis (CPH) for language acquisition, and some have sought to provide neurological explanations for such a period. Although the notion that there is a critical period for language acquisition is not new, it continues to generate a great deal of interest and debate and it is a topic ripe for neurolinguistic investigation.

The concept of a critical period, originating from work in embryology and ethology, is based upon the premise that there is a circumscribed period of time in the development of an organism during which it must be exposed to specific ex-
ternal stimuli or internal events if it is to develop normally. In addition, it has been proposed that a critical period should have an observable onset and offset and a specifiable duration (e.g., Mack 1997). Empirical investigations of the CPH have been conducted for years, as exemplified by Stockard’s 1921 study of fish embryo, the oft-cited work of Lorenz 1937 on bird imprinting, and Hubel and Wiesel’s acclaimed studies with the visual system of cats (e.g., Hubel and Wiesel 1963, 1970). Work such as this and the work of many others (see, e.g., Bornstein 1987) has amply demonstrated the existence of critical periods in animal studies. What remains disputed is the extent to which evidence based upon animal ontogeny is relevant to human behavior — specifically, to the acquisition of language. But before proceeding, it is important to clarify several points.

First, the term ‘critical period’ is often used interchangeably with the term ‘sensitive period’, and some researchers use the latter term when others would use the former (e.g., Bateson 1979). A general convention, however, is to use the term ‘critical period’ to denote a period that ends abruptly and ‘sensitive period’ to denote one that ends gradually. But it is quite difficult to operationalize ‘abruptly’ and ‘gradually’. For example, a 24-hour period of susceptibility to environmental influences would certainly seem to qualify as one that ends abruptly. Yet if that 24 hours represents 80% of the life span of the organism involved (as in an insect responding to pheromones in a mating cycle), the ending of the period might well be interpreted as gradual. In other words, ‘abrupt’ and ‘gradual’ are relative terms — a point almost never made in discussions of the CPH. Therefore, it seems more reasonable view a critical period as that time during which complete development (of a physical structure or a behavior) is possible, and a sensitive period as that time during which partial development is possible. Because studies designed to test the CPH in language-acquisition research invariably find evidence that at least some language acquisition can occur throughout the life span, the term ‘sensitive period’ (and ‘sensitive-period hypothesis’ or SPH) will be used in the present discussion.

Second, it is possible to assert that there are age-based (maturational) constraints on language acquisition without agreeing that these constraints are the consequence of neurobiological factors. For example, some second-language researchers have proposed that adult L2 acquisition is less successful than childhood L2 acquisition for reasons involving social, affective, personality, cultural, testing and/or pedagogical variables (e.g., Snow 1987; Singleton 1989; Brown 1994). Certainly, these variables and countless others contribute in some measure to age-based effects. But, because the focus here is on the role of brain-based language behaviors, maturational constraints are treated as NEUROBIOLOGICALLY based maturational constraints.

On a related note, it is possible to maintain that there are maturational constraints on language acquisition without positing the existence of a critical (or sensitive) period. For example, it might be the case that language proficiency correlates inversely with age at the onset of language acquisition (i.e., the younger one is when he/she acquires language, the more proficient he/she will be) and that an age-based decrement in proficiency is reflected as a linear function. If this were
the case, then acquisition at age 25 should result in better performance than acquisition at age 30, and acquisition at age 35 should result in better performance than acquisition at age 40. But to date, there is little evidence of this.

Finally, no strong distinction is made here between a sensitive period for a first or a second language. A number of studies designed to test the SPH for language acquisition have, in fact, been conducted using the L2 of bilinguals or second-language learners. Of course, there are many ways in which first-language (L1) and second-language acquisition differ. For example, apparent age-related difficulties — if they exist — in adult L2 acquisition may be due as much to transfer from the L1 as to biological constraints on late language learning. But, with the application of appropriate methods for testing and evaluation and the use of large numbers of subjects from different language backgrounds, it should be possible to control or account for at least some of the variance caused by non-maturational factors.

Some of the earliest observations about a sensitive (or, in their terms, critical) period for language were made by Penfield 1953 and Lenneberg 1967. Both maintained that there were maturationally based constraints on language acquisition, and Lenneberg clearly associated these constraints with neurological variables. However, two of Lenneberg’s proposals have not withstood empirical investigation although they are often cited as fact in the literature. These are (1) that the critical period for language acquisition ends at puberty, and (2) that the end of the critical period is correlated with or caused by an increase in the lateralization of language to the left hemisphere. (If there is a critical period, it probably ends much earlier than puberty, at least with respect to certain linguistic components and modalities. Furthermore, it is unlikely that there is a single critical or sensitive period for the entire linguistic system.) But importantly, Lenneberg (1967:176) also conjectures that ‘the time limitations postulated for language acquisition’ probably do not function ‘across the board for all types of human learning’. This is a central premise underlying most studies designed to test the SPH for language acquisition.

There is now such a large body of work on the relationship between age and language acquisition that much of the evidence cited to support the SPH is well known, so examples here will be kept to a minimum. Pertinent studies include the comparative analysis of brain damage in children versus adults (e.g., Robinson 1981); examination of language acquisition and behavior in language-deprived children and adults (Lane 1976; Curtiss 1977, 1994; Newport 1988, 1990; Emmorey et al. 1995; Grimshaw et al. 1998); and examination of neurological functions in individuals whose exposure to language occurred at different ages (Weber-Fox & Neville 1996; Neville et al. 1997, 1998). In addition, inferential support can be found in some psycholinguistic studies of individuals who acquired their L2 at different ages (e.g., Oyama 1976; Patkowski 1980; Johnson & Newport 1989; Flege 1991; Kim 1994; Shim 1995; Flege, Munro, & MacKay 1995; Munro et al. 1996; E. Kim 1997; Mack 1998: Mack et al. 1999). And, as will be considered in Section 3.3., relevant evidence is now emerging from brain-imaging studies of bilinguals.
A frequently cited study regarding the SPH and L2 acquisition was conducted by Johnson & Newport 1989 using 46 native speakers of Korean and Chinese who arrived in the U.S. between the ages of 3 and 39. Subjects were tested on a grammaticality judgment task (GJT) in English. Those who had arrived in the U.S. between the ages of 3 and 7 performed as accurately as did native speakers of English. Those whose age of arrival was 8 to 10 performed less accurately, those who arrived from age 11 to 15 performed even less accurately, and those who arrived after age 15 performed the least accurately. Johnson & Newport interpret their findings as support for the SPH not only because of these findings, but because age was a stronger predictor of subjects’ performance than were other variables examined, including duration of exposure to English and attitudinal and motivational variables. The findings of Shim 1995 and E. Kim 1997 who also used a GJT with Korean-English bilinguals differing in age of exposure to English supported the results of Johnson and Newport’s study although they observed earlier age-based effects. That is, subjects who were exposed to English as early as age 6 did not perform, in all respects, as did the native speakers to whom they were compared.

In an experiment designed to test the SPH for the phonological component, Mack 1998 and Mack et al. 1999 tested 15 adult English native speakers and 60 adult Korean-English bilinguals who were native speakers of Korean. The bilinguals were divided into four groups of 15 each, based upon age of arrival in the U.S. Subjects were required to discriminate and identify stimuli in computer-synthesized /i/-I/ and /u/-U/ continua. (These sets of vowels were used primarily because neither /I/ nor /U/ exists in the Korean vowel system.) To control for one potentially major confounding variable, ANCOVAs were used for the data analysis with length of exposure to English as the covariate. Results revealed that all five groups discriminated the vowels similarly, but differences emerged in their identification of the /i/-I/ continuum, with only those bilinguals who had been exposed to English between ages 4 and 7 performing as the native speakers did. (No difference in the identification of the /u/-U/ continuum was observed possibly because the bilinguals associated the English /U/ with the Korean high back un-rounded vowel.) Moreover, partial correlations revealed that age was more strongly correlated with /i/-I/ identification among the bilinguals than was duration of exposure to English, Korean proficiency self-rating, or the amount of Korean used in the home. Hence the results are interpreted as support for the SPH for language acquisition.

But there are even stronger sources of evidence for the SPH — and hence for maturationally based constraints on language acquisition — than these psycholinguistic studies of bilinguals. These can be found in studies detailing the language deficits of individuals whose exposure to a native (first) language did not occur until relatively late in life.

The most well-documented of these cases is that of Genie (Curtiss 1977) who, from the age of twenty months to thirteen years, was kept in isolation and received almost no linguistic input. At the time she was discovered and rescued
from her physical and social imprisonment, she could neither produce nor understand language. Yet, in response to intensive language therapy, within several months she could produce at least 100 words and she could combine words in simple utterances. Moreover, according to Curtiss (1994:228), Genie’s ‘acquisition of lexicon and the expression of meaning relations, including multipropositionality, steadily increased’. On the other hand, ‘her utterances remained largely agrammatic and hierarchically flat.’ And, Curtiss notes, ‘her speech, even after eight years, remained essentially devoid of “closed-class” morphology and of most syntactic devices and operations’. Clearly, Genie did not acquire a complete language system. Most interpretations of her linguistic abilities (or lack thereof) are based upon the notion that Genie’s ‘window of opportunity’ for acquiring language had closed at least partially by the time she was exposed to language.

Curtiss (1994:229) discusses a related case, that of Chelsea, whose language acquisition did not, through an unfortunate set of circumstances, begin until she was fitted with hearing aids when in her thirties. Like Genie, Chelsea was able to acquire lexical items fairly rapidly, but her multiword utterances were ‘almost without exception, unacceptable grammatically and quite often propositionally unclear or ill formed’. In contrast to Genie, Chelsea’s ‘lexical knowledge seemed limited to (denotative) definitional cores and [did] not appear to encompass either subcategorization information or logical structure constraints’. More recently, Grimshaw et al. 1998 presented the case of a hearing-impaired individual who was fitted with hearing aids at a relatively late age (although much earlier than Chelsea had been). The focus of their study was E.M., a young man who had been profoundly deaf since birth. At age 15, he was fitted with hearing aids and was then exposed to Spanish, the language of relatives with whom he resided, in a naturalistic context in the home. Yet, even after he had been exposed to spoken Spanish for four years, E.M. exhibited severe linguistic deficits and his MLU (mean length of utterance) was less than 2. (By contrast, as the authors point out, a normal four-year-old child has a mean MLU of 4.4.)

Taken together, evidence from studies such the above strongly suggests that there are maturational constraints on language acquisition and that there is a sensitive period for language acquisition. (See however Vargha-Khadem et al. 1997 on the acquisition of language by a nine-year-old child after left hemidecortication and Locke 1997 for a discussion of problems with the interpretation of the SPH.) But what how might these constraints be represented at the neurobiological level? At present, speculation must suffice, as the illustration below reveals.

In a recent publication, individuals involved in national policy-making organizations devoted to an understanding of child development stressed the role of neurological changes as they relate to early childhood (Melmed 1997; Newberger 1997). For example, Newberger (1997:5) asserts that, ‘if a child receives little stimulation early on, synapses will not sprout or develop, and the brain will make fewer connections. Therefore, a child’s experiences during the first few days, months, and years may be more decisive than scientists once believed’. Al-
though Newberger may be correct, she cites no supporting data (for example, from the study of infant and child brains) because the data simply do not exist. That is, to systematically relate numbers of synapses in young human brains to specific amounts of environmental stimulation would require healthy brain tissue obtained post-mortem and prepared for examination with electron microscopy. These samples would be taken from the brains of individuals who had been classified, prior to death, with respect to the amount of environmental stimulation received, such as no exposure to linguistic input, large amounts of linguistic input, etc. (An even better design would entail the random selection and random assignment of subjects to groups whose environmental stimulation was then carefully controlled.) Such a study is theoretically feasible but, especially for methodological reasons, it would be difficult to implement.

In fact, some the best evidence currently available regarding the effect of experience on cellular changes in the brain has been obtained in animal studies (e.g., Greenough 1986; Greenough et al. 1987; Greenough & Black 1992). Greenough and colleagues conducted studies of rats raised in a variety of environments. As Greenough et al. 1987 explain, they studied environmental complexity (EC) rats, social cage (SC) rats, and individual cage (IC) rats. The EC rats were housed with others and had ready access to play objects; the SC rats were housed in small groups or pairs in nearly empty cages; and the IC rats were alone in cages and had no play objects. Morphological examination of the animals’ brains revealed that the EC rats had about 20% more dendrites (and hence about 20% more synapses) per neuron in the upper visual cortex than did the IC rats. This amounts to about 2,000 synapses per neuron. (When one recalls the size and density of neurons, the magnitude of this effect becomes especially apparent.) This type of experience-based change is termed by Greenough et al. (1987:550) to be an ‘experience-dependent process’—one characterized by the development of new synapses (synaptogenesis). They contrast this with an ‘experience-expectant process’ as follows:

The data ... suggest that there is a fundamental difference between the processes governing the formation of synapses in early, age-locked sensory system development and those governing synapse formation during later development and adulthood. Experience-expectant processes found in early development appear to produce a surplus of synapses, which are then pruned back by experience to a functional subset. In later development and adulthood, synapses appear to be generated in response to events that provide information to be encoded in the nervous system.

Thus the susceptibility of the brain to certain types of extrinsic influence is maturationally based and involves synaptic pruning (elimination of synapses). This may be the neurological substrate of a sensitive period for language acquisition (and one of the reasons why, after childhood, second-language learners almost invariably exhibit an accent in their L2!). While such a suggestion may seem speculative, Greenough et al. (1987:553) make a related point:
A conjecture that a particular developmental process has a sensitive period(s) (e.g., language acquisition) can now generate testable hypotheses about neural changes that must accompany it. For example, a fixed time course for language acquisition would suggest a peak in cortical thickness of synaptic numbers shortly before the start of a hypothetical experience-expectant period.

This proposed hypothesis provides a compelling argument for the neurobiological study of a proposed sensitive period (or periods) for language and, in fact, finds some empirical support in the work of Huttenlocher & Dabholkar 1997 who studied synaptogenesis in the auditory and prefrontal cortices of fetal, infant, and child brains. Among their major findings were that neither synapse formation nor synapse elimination followed one time course in all regions of the cortex and, in the auditory cortex (but not in the prefrontal cortex) synapse elimination appeared to be complete by the age of 12. They also note that ‘synapse elimination, in contrast to synaptogenesis, seems to be … environmentally related’ (117). In this regard, they refer to findings of permanent visual defects resulting from visually deprived input occurring during a period of synapse elimination. It appears then that synapse elimination (as in experience-expectant processes) is a crucial neurological feature associated with sensitive (or critical) periods.

Thus empirical evidence is emerging that may eventually support (or refute) the sensitive-period hypothesis for language acquisition. What is now needed are (1) additional age-based studies to better determine developmental milestones in language behaviors (such as the well-documented early-childhood loss of the ability to discriminate non-native speech sounds [Werker & Tees 1984; Werker 1997]), and (2) the correlation of such milestones with changes in the brain. Results of such studies could also be used to help reconcile apparent discrepancies between the above-cited work and evidence from neuroimaging (see 3.4. below) regarding age-related effects and the brain.

3.2. Einstein’s brain: Is there a language module?

Recently, Albert Einstein was featured in news reports on national television, on the radio, and in news magazines. Or, more accurately, Albert Einstein’s brain was featured. Sandra Witelson and colleagues have been studying Einstein’s brain (kept, in a remarkable act of foresight, by the pathologist who conducted the autopsy after Einstein’s death in 1955). Their objective has been to determine if his brain has any anatomically distinct characteristics — characteristics that could be related to the type and or extent of his intellectual abilities.

These researchers found that, while the overall size of Einstein’s brain was within the range of the brains to which his was compared, one region in the parietal lobe, the parietal operculum, was absent and the inferior parietal lobule was 15% larger than average (Witelson et al. 1999). This lobule provides for associations across sensory, visual, and somesthetic modalities and has been implicated in visuospatial, mathematical, and ‘imagery of movement’ cognitive functions. Witelson et al. suggest that its apparent enlargement in Einstein’s brain may be causally related to his intelligence and, more specifically, to the way in which Ein-
stein conceptualized scientific problems. In other words, researchers may have discovered the neurological substrates of the theory of relativity.

Of course, proposing a causal connection between neuroanatomy and cognitive function can be problematic. In this case, for example, Einstein’s vibrant life-long intellectual activities may have stimulated the development of neural networks (although Witelson et al. indicate that the extensive development of Einstein’s posterior parietal lobes probably occurred early in development). It is also possible that the unusual structure of Einstein’s brain is an anatomical accident completely unrelated to his cognitive abilities. But, as this discovery suggests, the linking of highly specific brain regions to highly specific brain functions is not only tempting but is, at least in part, warranted on the basis of what has long been known about the relationships between brain structure and function.

Consider again the work of Ojemann and colleagues (Ojemann 1980, 1981, 1983, 1994; Ojemann & Whitaker 1978; Ojemann & Mateer 1979). This work, using electrocortical stimulation to map the relationship between brain regions and language functions, has yielded some provocative results largely supportive of a highly locationist interpretation of language organization and function. For example, Ojemann found that ‘at a few sites [in the cortex] only conjunctions, prepositions, and verb endings were altered during stimulation’ (Ojemann 1983:71-2). Such an assertion is somewhat difficult to accommodate in light of Ojemann’s own acknowledgment of frequently observed between-subject variability in the cortical representation of language (Ojemann et al. 1989; Ojemann 1994). Still his work remains widely cited and has even inspired studies designed to determine whether or not a bilingual’s two languages have distinct spatial representations in the brain (e.g., Rapport et al. 1983).

In fact, a related type of cortical mapping is now being used to assist neurosurgeons in delineating brain regions responsible for various functions (Grimson 1999). With this procedure, a transcranial magnetic stimulator with a pair of electromagnets induces electrical currents in specific regions of the brain, such as the motor cortex. Electrical ‘pickups’ affixed, for example, to a patient’s hand can then reveal to what extent muscles respond to cortical stimulation, thereby enabling the surgeon to distinguish brain regions which generate the strongest responses from the more peripheral regions which generate weaker responses. Application of this procedure helps reduce the likelihood of paralysis which could result if core regions of the primary motor cortex were excised during neurosurgery.

Localization of neurological functions is similar, but not identical, to the theory of modularity that gained prominence in the 1980s. A modular cognitive system, as articulated by Fodor (1983:37) is ‘domain specific, innately specified, hardwired, autonomous, and not assembled’ (i.e., the system has not been ‘put together from some stock of more elementary subprocesses’). And, for decades, Chomsky (1972, 1984, 1986) has premised his theories upon a view of the language faculty as modular or ‘informationally encapsulated’. He states (1972:70) that ‘as far as we know, possession of human language is associated with a spe-
cific type of mental organization, not simply a higher degree of intelligence’. And, in a discussion of Chomsky’s theory of language and the mind (and, more specifically, of his conception of the principles of Universal Grammar) Cook (1988:20) says the following:

It is not at all clear that ... UG [Universal Grammar] principles could operate in areas of the mind other than language. Speakers can entertain mathematical or logical possibilities that [unlike language] are not structure-dependent. ... The language faculty has particular properties that do not belong to other faculties. Further arguments for independence come from language acquisition; principles such as structure-dependency do not appear to be learnable by the same means that, say, children [use when learning] to walk or to do arithmetic.5

In recent years, evidence from selectively impaired and preserved language functions has been cited as support for an interpretation of language as a modular system — and one which may be composed of sub-modules. For example, Curtiss (1982, 1988) presents the case of a child who had pervasive mental retardation accompanied by motor, social, and cognitive delay but showed evidence of preserved linguistic abilities. She also cites the cases of three four-year olds, all exhibiting normal conversational abilities but deficits in morphosyntax as revealed in such utterances as, Him bite mine head off, He little than me, and Want go show Papa (1988:89). To account for such evidence, Curtiss 1994 proposes a tripartite model of language comprising a grammatical, referential/propositional, and social/communicative component — each one of which may be selectively impaired or preserved.

Yet modularity has not been embraced by all researchers in the neurosciences and linguistic sciences, as Lieberman (1984:21) makes eminently clear:

The human brain is a complex, interconnected structure that has a long evolutionary history. It was not designed by a team of engineers who were aiming to produce a device that would operate by using discrete modules that each independently carried out the computations for some cognitive act. The data that have been acquired by neurophysiologists are not consistent with the assumption that the human brain functions by using discrete ‘modules’ — that is neural devices like a language module, a space perception module, a number system module — that abruptly evolved as Chomsky ... proposes.

Farah (1994:46) takes a related position by using the parallel distributed processing (PDP) framework proposed by Rumelhart & McClelland 1986 ‘as a source of principled constraints on the ways in which the remaining parts of the [neural] system behave after local damage’. The components of this model, as applied by Farah, are that (1) the representation of knowledge is distributed rather than localized; (2) information is processed in a graded rather than in an all-or-none manner; and (3) the units in the system function interactively rather than in isolation. On the basis of work conducted with McClelland (Farah & McClelland 1991) in which a computational two-component (visual and functional) model of
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semantic memory was lesioned, Farah (1994:50) concludes that damage to the visual semantic system results in impairment in the (non-damaged) functional semantic system — a finding contrary to the ‘locality assumption’. She provides further evidence, based upon computer models, in support of the PDP framework and, in so doing, concludes that the locality assumption and at least certain interpretations of language modularity are not tenable.

This approach is related to a connectionist model of language (Dell 1985; Elman 1991; Plaut 1995; Nobre & Plunkett 1997). A highly simplified description of connectionism is that it represents cognitive functions, such as language processing, using interactive neural networks. These are activated as a function of the strength (‘weights’) of the connections among (in some approaches) various types of nodes, such as word or feature nodes. Nobre & Plunkett (1997:263) state that, by demonstrating ‘how a high degree of integration can be achieved across disparate knowledge domains’, connectionist modeling ‘challenges the commonly held assumption that the fractionation of behavior [including linguistic behavior] reflects an underlying fractionation of the brain systems that control such behavior’.

Another point is that while, for some researchers ‘modularity’ is simply a terminological variant of ‘locationism’, for others it is deemed particularly insightful because it interprets linguistic deficits within the framework of specific theories of grammar and/or models of knowledge representation (e.g., Rapp & Caramazza 1997; Smith forthcoming). However, it must be emphasized that, as originally formulated, modularity was a theory of the mind, not of the brain. Moreover, the term has been used, sometimes confusingly, in various ways. As Lieberman (1998:109) points out, ‘Neurophysiologists often use module to characterize a functional neural circuit that carries out a particular task’ while linguists may use the term to refer to ‘a genetically specified part of the brain that carries out some specific aspect of behavior, such as coding the rules of grammar.’ In addition, it is possible that certain cognitive processes may be FUNCTIONALLY modular while being subserved by massively interconnected neural networks. In conclusion, as Karmiloff-Smith 1992 proposes, a reasonable theory of cognition may ultimately need to encompass both domain-specific nativist and domain-general empiricist interpretations. In such a system, modular and non-modular approaches to knowledge are not treated as mutually exclusive but as complementary. Emerging findings from the neurosciences can help determine whether or not such an interpretation is reasonable and, if it is, how it can be applied to linguistic theory.

3.3. A new window on the brain: Insights from neuroimaging

The past two decades have witnessed an energetic emergence and enthusiastic application of a variety of brain-imaging techniques. (For general overviews and descriptions see Binder & Rao 1994; Raichle 1994; Toga & Mazziotta 1996; Zatorre et al. 1996; Lester et al. 1997.) These techniques have, at last, permitted researchers to obtain high-resolution images of intact brains using relatively non-invasive procedures. Some of these procedures are CT (computerized tomogra-
phy), MEG (magnetoencephalography), SPECT (single-photon emission tomography), PET (positron-emission tomography), NMR (nuclear magnetic resonance) and fMRI (functional magnetic resonance imaging). Capable of providing detailed maps of the brain, these revolutionary techniques have been increasingly used since the early 1980s. This is clearly revealed in the following figure presenting the number of studies in a standard database referring, over a five-decade period, to a once highly utilized procedure — dichotic listening — and to newer techniques involving brain imaging.

![Graph showing the number of studies referring to dichotic listening and brain imaging](image)

Figure 3: The total number of studies referring to dichotic listening and brain imaging, by decade, found in the PsychInfo database. Note the complete absence of references to brain imaging up to 1980, followed by a dramatic increase from 1980 to 1999. Concurrent with this is a marked decrease, particularly in the past decade, to studies referring to dichotic listening.

One type of ‘map’, the CT scan (developed in the early 1970s), is obtained by passing a beam of x-rays through the brain (or other tissue) at many angles through a specific plane and then reconstructing the resulting information as a three-dimensional image. Computerized tomography provides information based upon the density of the tissue observed. Thus the CT scan can clearly reveal anatomical features of soft tissue and is particularly well suited for locating brain lesions. Two other scanning techniques, PET and fMRI, have generated particular interest because, by revealing changes in metabolic activity resulting from experimentally manipulated cognitive and behavioral tasks, they can be used for obtaining images of the intact DYNAMIC brain. Put simply, they can take a picture of a resting brain, a thinking brain, a listening brain, a visualizing brain, even an obsessive-compulsive brain.

Specifically, PET utilizes a technique in which (for example) water is labeled with a radioisotope injected into a vein. Certain activities result in an increase of regional cerebral blood flow (rCBF); PET detects the radioactive material and takes multiple pictures of the functioning brain, revealing changes in activity with an accuracy of within several millimeters. (It does, however, have relatively poor
temporal resolution.) Similarly, fMRI scans are generated through, in one method, the detection of small fluctuations in the magnetic properties of oxygen-carrying hemoglobin (Raichle 1994). Thus, fMRI reveals changes in metabolic activity in the brain, and it does so with a high degree of spatial resolution. It can also be combined with a standard MRI so that both structural (anatomical) and functional information is represented. Moreover, because fMRI does not involve the introduction of a radioactive substance, multiple scans can be obtained from one individual resulting in increased precision (Banich 1997). Particularly in the past decade, both PET and fMRI have provided valuable data about how the brain processes language (e.g., Metter 1991; Fiez & Peterson 1993, Klein et al. 1995; Damasio et al. 1996; Habib & Démonet 1996; Stromswold et al. 1996; FitzGerald et al. 1997; Friedman et al. 1998; Zatorre forthcoming).

For example, one PET-based study has recently been conducted by Jaeger et al. 1996 to test competing models of past-tense formation in English. As they state (1996:454) single-system theories posit that both the regular and irregular past tense are handled 'by a single cognitive mechanism or system,' while dual-system theories propose 'that regular and irregular past tense production are each handled by a separate cognitive mechanism or system.' In the latter case, regular past tense verbs could either be generated by rule while irregular past tense forms are stored in the lexicon with their stems (Pinker 1991), or regular and irregular verbs could be generated by two different submodules for each of the rule types (Ling & Marinov 1993). The prediction made by Jaeger et al. is that dual-systems theories entail two processes that are so computationally distinct that they should be subserved 'by functionally different systems' (457).

Thus, in the Jaeger et al. study, subjects read aloud regular and irregular verb stems as well as nonce forms and were required to produce the past tense form of the words. A major finding was that the irregular past resulted in activation of the largest region of the brain (and in the longest reaction times). The authors conclude that their findings are consistent with dual-systems theories and inconsistent with single-systems theories (and connectionist models). Although a subsequent critique of this study (Seidenberg & Hoeffner 1998) claims that it is theoretically and methodologically flawed, the findings are supported in a study of a lexical-decision test with priming administered to aphasics (Marslen-Wilson & Tyler 1997). Regardless of the ultimate interpretation of the status of past-tense formation in English, the use of PET to address this issue represents a valiant attempt to apply neuroimaging in testing competing hypotheses about how the brain processes certain types of linguistic information.

In an fMRI study, Binder et al. 1997 have addressed a somewhat different linguistic topic — namely, the identification of as many of the receptive language regions of the brain as possible, thereby testing the ‘classical model’ of language localization. Subjects were required to make decisions about two types of auditorily presented stimuli. In one condition, they were to indicate by key press when they heard any sequence of two 750-Hz tones; in another condition they were to indicate by key press which of the nouns presented (all names of animals) designated animals both native to the U.S. and used by humans.
Results revealed extensive bilateral activation, both cortically and subcortically, on the tone-decision task. Areas more strongly activated in the semantic-decision than in the tone task were found almost exclusively in the left hemisphere or right cerebellum, and the researchers observed quite extensive activation of regions in the left frontal lobe — regions ‘historically considered responsible for language production’ (355). They further conclude that ‘left frontal regions may participate in receptive language processing in the normal, uninjured state, playing a “language executive” role in coordinating the sensory and semantic processes occurring in posterior areas’ (359). In this case, neuroimaging may provide important information about language organization in the intact brain, since these results are not entirely consistent with those obtained from studies of language impairment.

What is apparent from both of these neuroimaging studies, as well as from scores of other related studies now underway, is that functional brain imaging is the preferred research technique (for relating brain structure and function) of the present and the wave of the future. Objections about its application are faint and few. Yet the psychologist, Richard DeGrandpre, maintains that the use of brain scans can ‘promote a dangerous institutional bias toward neurological reductionism, ... by implying that any simple physiological correlate of behavior is good evidence of cause’ (1999:15). But until the fundamental assumptions underlying the interpretation of brain scans prove invalid, studies using these techniques will continue to proliferate at an exponential rate. The temptation to peer, at long last, inside ‘the black box’ is simply too great, the technology is too dazzling, and the observations are too exciting for anyone to abandon — or even seriously question — this research paradigm in the foreseeable future.

3.4. The bilingual brain

For years, researchers have been intrigued by the co-existence of two languages in one brain. The questions most often asked are deceptively straightforward: (1) How are a bilingual’s languages functionally and/or anatomically organized? (2) How and to what extent are a bilingual’s languages kept separate? To date, countless studies using a variety of methodologies — particularly in the fields of psycholinguistics and neurolinguistics — have been undertaken in an attempt to answer these questions (e.g., Paradis 1985, 1987, 1989, forthcoming; Paivio & Desrochers 1980; Rapport et al. 1983; Potter et al. 1984; Mack 1984, 1988, 1989, 1992; 1998; Nilipour & Ashayer 1989; Flege & Eefting 1987; Flege 1993, 1995; Mack et al. 1995; Wulfeck, Bates, & Capasso 1991; Schmidt & Flege 1995; Kim et al. 1997; Mack et al. 1999). Among the most promising avenues of research are the (continued) study of language behavior in bilingual aphasics and the examination of the brains of normal healthy bilinguals using neuroimaging.

Michel Paradis’ seminal 1977 description of patterns of language loss and restitution, based upon case studies of 138 bilingual aphasics, was a clear manifestation of over a century of interest in and research on language deficits in bi- and multilingual aphasics (e.g., Ribot 1882; Pitres 1885; Gloning & Gloning 1965; Minkowski 1965; Albert & Obler 1975; Lebrun 1976; Paradis 1977, 1983, 1987,
1989, forthcoming; Paradis et al. 1982; Paradis & Goldblum, 1989; Eviatar et al. 1999; Roberts & Deslauriers 1999). The work of Paradis and others has garnered considered attention because it is now clear that information from aphasiology can provide insights into how languages are organized, functionally and/or anatomically, in the bilingual brain.

Specifically, Paradis 1977 identified five basic patterns of language loss and restitution in bilingual aphasics — synergistic (subdivided into parallel and differential), successive, selective, antagonistic, and mixed. He describes these as follows (1989:117):

Recovery is said to be parallel when both (or all) languages are similarly impaired and restored at the same rate; differential when impairment is of a different degree in each language relative to premorbid mastery; successive when one language does not begin to reappear until another has been maximally recovered; antagonistic when one language regresses as the other progresses; selective when patients do not regain the use of one or more of their languages; and mixed when patients systematically [but inappropriately] mix or blend features of their languages at any or all levels of linguistic structure.

As of 1989, Paradis had described three more types — alternate antagonistic, differential aphasia, and selective aphasia. An alternate antagonistic pattern is characterized by the patient’s temporary and alternating inability to produce one or the other of the two languages. In differential aphasia, the patient exhibits symptoms typical of one type of aphasia in one of the languages and of another type in the other language. (See however a reanalysis of this type in Paradis 1998.) Selective aphasia occurs when a patient has ‘obvious impairments in one language without any measurable deficit in the other(s)’ (Paradis 1989:117).

In an attempt to account for the observed patterns of language deficit and preservation in bilingual aphasics, Paradis 1987, 1998 has posited four hypotheses, each of which makes different claims about the neural substrates underlying the bilingual’s languages. These are the Extended System, Dual System, Tripartite, and Subset Hypotheses. Paradis (1998:47) maintains that, of the four, only the Subset Hypothesis is compatible with all patterns of bilingual aphasia (as well as with ‘unilingual phenomena’) reported to date. This hypothesis is based upon the premise that ‘each language constitutes a subsystem of the larger cognitive system known as language, in the same way that various registers constitute subsystems of the overall language competence of an individual’. And ‘each subsystem can be selectively impaired by pathology’.

On the other hand, Paradis frequently takes pains to distinguish between the functional and anatomical organization of language. For example, in discussing selective language impairment in a trilingual patient, he maintains (1987:342) that ‘selective impairment does not necessarily suggest different anatomical substrates for the representation of two languages’. To illustrate, he cites a case of selective aphasia in which only one of the patient’s three languages exhibited aphasic symptoms postoperatively. This language recovered spontaneously, yet
one of the previously unimpaired languages then became impaired. He observes, ‘It is unlikely that the two affected languages exchanged location over this period’.

Green’s ‘inhibitory control model’ 1986, 1993 can account for such a selective type of impairment, for it proposes the following:

Two classes of resource [are] identified: excitatory resources which can be used to increase the activation level and inhibitory resources which can be used to decrease the activation level. In producing or comprehending speech, resources are used up and unless they are replenished the system will fail. One effect of brain damage, or other stressors, is to reduce the availability of resources. According to the framework, individual performance is constrained by the availability of resources to effect the control of activation levels (1993:262-3).

Paradis similarly accounts for a pattern of language loss such as the one described above using the ‘activation threshold hypothesis’. This hypothesis proposes that the ability to perceive or produce a linguistically meaningful unit may be impaired not due to its complete absence, but due to the improper functioning of neural networks responsible for activating traces left (in this case) by linguistic experience. The advantage of Green’s and Paradis’ hypotheses is that they can account for impaired language behavior in bilinguals, such as inadvertent mixing of the languages, as well as the behavior of normal bilinguals, such as volitional code-switching. Still it must be acknowledged that some aphasias — in any type of language user — are due to a substantial loss of neural tissue. In such cases, regions subserving language may be destroyed to the extent that no amount of activation or resource allocation can compensate.

It should also be noted that some researchers initially proposed that at least one of the bilingual’s two languages might be subserved by, or actually located in, the right hemisphere (e.g., Gloning & Gloning 1965; Albert & Obler 1978). Such separation of the two languages would help explain, for example, the observed loss or preservation of (only) one of the languages in some bilingual aphasics. However, such a gross anatomical distinction in the neural representation of the two languages has not been supported by recent studies (e.g., Rapport et al. 1983; McKeever & Hunt 1984; Berthier et al. 1990: Chee et al. 1999). Indeed, most now believe that a bilingual’s two languages are subserved by the same hemisphere (usually the left) and that interesting neurologically based features of bilingual language organization will be observed as intra- (rather than inter-) hemispheric differences or similarities.

In light of admitted difficulties associated with ‘locating’ language in the brains of bilingual aphasics (see, for example, the excellent discussion by Zatorre 1989), it is not surprising that neuroimaging is now being used, with increasing frequency, to help address fundamental questions about the neurological substrates of language in the intact bilingual brain.

An already notable neuroimaging study has recently been conducted by Kim et al. 1997. Its objective was to determine if, among bilinguals, age at the on-
set of the acquisition of the two languages affects the cortical representation of those languages. Thus, using fMRI, these researchers compared the extent of spatial separation of the languages in bilinguals who had acquired both languages in infancy (termed ‘early bilinguals’) and in bilinguals who had acquired their first language in infancy and a second language in adolescence or early adulthood (termed ‘late bilinguals’). The regions examined were the ‘classic’ language areas — Broca’s area in the inferior frontal gyrus (Brodmann’s area 44 and, for one subject, areas 44 and 46) and Wernicke’s area in the superior temporal gyrus (Brodmann’s area 22). Spatial separation was operationalized as the center-to-center distance in millimeters (mm) between centroids of activity as measured during linguistic tasks carried out in the subjects’ two languages. To minimize artifacts resulting from head movement, yet to engage subjects in a language-based task, the researchers had the subjects use internal speech in each of their two languages to describe, without vocalizing, what they had done at a specified time the previous day.

Results revealed no difference in the distance between the center-of-mass centroids in Wernicke’s area for the two languages of the early and late bilinguals, with the mean amount of spatial separation being 1.6 mm for the early bilinguals and 1.9 mm for the late bilinguals. But a substantial difference was observed for the two groups in Broca’s area. Here the mean amount of spatial separation was 1.5 mm for the early bilinguals and 7.4 mm for the late bilinguals. These researchers conclude that, at least with respect to Broca’s area, the early acquisition of two (native) languages may result in the use of a common language area responsible for phonetic processing and may render the two languages relatively impervious to subsequent neural modification. On the other hand, late acquisition of a (second) language may necessitate the utilization of additional cortical tissue since, presumably, language in the core area cannot be reorganized.10 These results obtained regardless of the handnesses or gender of the subjects, and across a variety of language pairs examined. (They are also reminiscent of the findings obtained in the electrocortical stimulation study of Ojemann & Whitaker 1978.)

Related results have been obtained from other neuroimaging studies of bilinguals. For example, in their pilot fMRI study of five multilinguals, all of whom were fluent in a native and second language but non-fluent in a third, Yetkin et al. 1996 found that the largest regions of fronto-parietal and frontal lobe activation were associated with speech production in the third (non-fluent) language. And the smallest regions of activation were associated with speech production in the two fluent languages. (For all subjects, the non-fluent language had been used for fewer than five years and was not, at the time of testing, used regularly.) Thus, for the two fluent languages, the regions of activation appeared to be more centralized.

Although not designed to evaluate the extent of cortical involvement in a bilingual’s two languages, an fMRI study conducted by Schlosser et al. 1998 also yields indirect support for the notion that a more familiar language results in stronger activation of frontal brain regions than does an unfamiliar one. They provided fourteen subjects with auditorily presented sentences in English (the
subjects’ native language) and in Turkish (a language which none of the subjects understood). While the English sentences produced strong left-superior sulcus activation in all subjects, the Turkish sentences evoked no coherent pattern of activation in any of the subjects.

Based upon these studies, it seems that language fluency — as reflected in age of language acquisition, years of language study and/or use, and language familiarity — is a crucial determinant of the neural representation of the languages of a bilingual. This conclusion finds at least indirect support in the work of Perani et al. 1998 who carried out a study, using PET, of high-proficiency early and high-proficiency late bilinguals. They found that, regardless of age of acquisition, all subjects appeared to utilize the same neural substrates, as reflected in left-hemispheric foci of activation, when listening to stories told in their two languages. A similar finding was obtained by Chee et al. in their 1999 fMRI study of the processing, by 24 Mandarin-English bilinguals, of single visually presented words. They conclude (1999:3052) that ‘common cortical areas are activated when fluent Mandarin-English bilinguals perform cued word generation. This is true of early, as well as late, onset bilinguals’. Again, while the bilinguals differed in age of L2 acquisition, all used English and Mandarin on a daily basis and all were characterized as fluent in both languages.

Clearly, brain-imaging studies designed to reveal the functional representation of languages in the bilingual brain have a promising future. These should prove especially revealing when their results are combined with data obtained from other approaches such as the study of aphasias in bilinguals.

In 1953, Uriel Weinreich presented a linguistically based model of ‘languages in contact’ by proposing three ways in which a bilingual’s language systems could be related to one another. He classified these as Types A, B, and C. For example, Type A would obtain if the bilingual had two separate representational systems for units in each language, Type B if there were two shared systems, and Type C if one system were subserved by or mediated through another. These types later came to be known as coordinate, compound, and subordinate bilingualism, and numerous studies were conducted to compare the psycholinguistic performance of, for example, coordinate and compound bilinguals. Weinreich’s typological constructs now appear naively simplistic. Moreover, the terms ‘coordinate’, ‘compound’, and ‘subordinate’ have fallen out of use, in part because they are difficult to validate empirically (at least as originally formulated). Yet analysis of the organization of the bilingual’s two languages is as warranted today as it was nearly fifty years ago. All that is required is a simple emendation of one of the questions underlying Weinreich’s work. That is, in addition to asking, ‘How are a bilingual’s two languages represented as LINGUISTIC systems?’ researchers can now ask, ‘How are a bilingual’s two languages represented as NEURO-FUNCTIONAL and NEUROANATOMICAL systems?’ Answers are already appearing on the horizon.
3.5. Y2K and beyond: Other developments

Three decades ago, Roman Jakobson — insightful, creative, and prescient — stated that ‘the deepest discernment of the relation between the human organism and its verbal abilities and activities is achieved by the mutual help of NEUROBIOLOGISTS [sic] and linguists in a comparative inquiry’ (1971:688). A major objective of the above discussion of new and emerging issues and techniques has been to demonstrate the importance of such ‘mutual help’. Thus four particularly promising areas of research have been discussed — areas in which the neurosciences have informed, and are likely to continue to inform, the linguistic sciences. These include maturational effects on language acquisition, language modularity (and connectionism), neuroimaging techniques, and the bilingual brain.

Yet as important as each of these is to the future of linguistics, this is hardly an exhaustive list with which one can march confidently into the new millennium. Other topics which may prove particularly fruitful in the coming years are these: (1) continued study of the role of genetic versus environmental factors in child language acquisition; (2) additional examination of the contribution of the right hemisphere (as well as subcortical and cerebellar structures) to language use; (3) application of techniques involving neurogenesis — the growth of new neurons — in older brains (once thought an impossibility) to human brains; and (4) determination of the extent to which research in Artificial Life (the computational modeling of cognitive processes as biological phenomena) can provide insights relevant to theories of language development and evolution.

4. Conclusion

In the Introduction above, some of history’s more blatant misconceptions about the role of the human brain were presented. Given the complexity of the brain’s functions and the extremely small scale of its basic building block, the neuron, it is hardly surprising that ancient philosophers and physicians had major misconceptions about what the brain does and how it does it. Indeed, as Crick (1994:3) points out in his book, The Astonishing Hypothesis, each of us is ‘no more than the behavior of a vast assembly of nerve cells and their associated molecules’, a fact that went unrecognized for thousands of years.

Nonetheless one of the ancients did, at least in part, get it right. In a commentary attributed to Hippocrates, glimpses of an early understanding of the function of the brain are clearly revealed:

The source of our pleasure, merriment, laughter and amusement, as of our grief, pain, anxiety and tears, is none other than the brain. It is specially the organ which enables us to think, see and hear, and to distinguish the ugly and the beautiful, the bad and the good, pleasant and unpleasant (Lloyd 1978:248).

Thus, even more than 2,000 years ago, ‘the father of modern medicine’ recognized the remarkable function of the ‘vast assembly’ residing inside the head. It is now axiomatic that without the brain there can be no emotion, thought, or lan-
language and that, without an understanding of the brain, there can be no complete understanding of emotion, thought, or language.

Also considered above have been selected developments in the neurosciences which have had a significant impact on the linguistic sciences. Information from the neurosciences has been emerging at an ever-accelerating rate, relegating Jakobson's 1973 observation that 'so far, almost nothing is known about the internal network of verbal communication' to the dustbin of history. Thus, although one author states that 'faculty members have long been blissfully ignorant about the folks in the building next door' (Nelson 1998:3), most linguists are not only aware of the folks in the building next door (in this case, the neuroscientists) but are happy to have them as neighbors.

Moreover there is now an increasing awareness of the importance of cross-disciplinary interaction among a variety of fields, as Edward O. Wilson makes clear in his book, Consilience: The Unity of Knowledge. Borrowing from William Whewell's 1840 work, The Philosophy of the Inductive Sciences, Wilson maintains that intellectual inquiry must be based upon 'consilience' or the 'jumping together' of knowledge across disciplines. He even advocates a grand theory of knowledge which entails no less than the unification of the sciences and humanities.

Whether or not Wilson's 'grand theory' will be realized, it is apparent that, although the Decade of the Brain is drawing to a close, coming decades will witness a plethora of new discoveries and insights from the neurosciences. And some of these discoveries and insights will provide answers to abiding questions about how language is organized and how it functions in the brain. Yet, as this new age of interdisciplinary exploration dawns, the words of the noted author Arthur Koestler (1967:254) come to mind: 'Once a scientist loses his sense of mystery, he can be an excellent technician, but he ceases to be a savant.' It is hoped that, even as researchers in the neurosciences and linguistic sciences cast about in seas roiling with new information, hypotheses, models, and theories, they will retain a sense of mystery about the human brain — and about how language at once inhabits, shapes, and reflects our remarkable 'universe within'.

NOTES

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Interestingly, Galen was not only an accomplished physician, but a philosopher and logician who discussed the concepts of ambiguity and fallacy, and who had a theory about spoken and written language (Edlow 1977).

Examination of aphasia in terms of Broca’s and Wernicke’s aphasia is known as the ‘classical view’ of aphasia. Yet it has long been known that (1) there are several to many other types of aphasia depending upon one’s classification criteria (Doody 1993); (2) pure forms of Broca’s and Wernicke’s aphasia are relatively rare; and (3) at least for Broca’s aphasia, ‘the underlying pathology is ... extensive and varied’ (Alexander et al. 1989:676). Thus, although this basic dichotomous typology is still widely cited and utilized, its inherent limitations must be acknowledged.

It should be noted that cortical mapping using electrocortical stimulation was not done capriciously. Mapping was originally conducted prior to the excision of areas believed to be causing epileptic seizures, permitting a ‘safer and more exact’ cortical excision (Penfield & Roberts 1959:107), although its value in mapping the language areas soon became apparent.

Moreover, it has long been recognized that the two hemispheres of the brain are anatomically asymmetrical and that, in most individuals, the planum temporale is larger on the left than the right (Geschwind & Levitsky 1968; Witelson 1977; Kertesz & Naeser 1994) — a feature which may be related to left-hemisphere specialization for language.

Structure-dependency, one of the first principles proposed in the UG approach, is based upon an interpretation of how elements of a sentence are moved. For example, to form a passive sentence, the direct object is moved to sentence-initial position (Jane loves cats → Cats are loved by Jane). This movement necessitates knowledge of the structural relationships among lexical items rather than the sequence in which they occur. For example, there would never be a rule (in English or any other natural language) such as, ‘To form the passive, move the n<sup>th</sup> word in the sentence to sentence-initial position.’ It must be noted that movement rules have undergone substantial re-evaluation and reformulation in the past several decades, although this example still suffices for illustrating the nature of principles in UG.

Magnetic resonance imaging is derived from a technique called nuclear magnetic resonance imaging (NMR) which yielded its developers, Felix Bloch and Edward Purcell, a 1952 Nobel Prize. Less than two decades later, Allan Cormack and Sir Dogfrey Housfield received a Nobel Prize for their work on the CT. Clearly, the development of enhanced <i>in vivo</i> imaging techniques represented a major milestone in the neurosciences — one whose importance was appropriately recognized by the scientific community.

In the present discussion, the term ‘bilingual’ is used to denote an individual who is reasonably fluent in two or more languages. (See Mack 1997 for further definitions pertaining to bilingualism.)
For extensive reviews of the literature also see Paradis 1977, 1989, and Albert & Obler 1978; for selections from primary sources on the topic see Paradis 1983; and for discussion of the limitations of cross-linguistic research in aphasia see Bates et al. 1991.

In fact, Paradis’ 1987 Bilingual Aphasia Test has been administered in over 60 language pairs to thousands of bilinguals worldwide and is now yielding significant findings about language loss and restitution in bilingual aphasics.

In a seemingly prescient observation about the organization of language in the brains of bilinguals, Pitres (1895:895) states that ‘on pouvait supposer que, le pied de la troisième circonvolution frontale contenant la totalité de l’appareil utilisé par l’acquisition de la langue maternelle, le reste de cette circonvolution restait libre pour l’acquisition des autres langues’. That is, he surmised that a portion of the third frontal convolution, a region in Broca’s area, is allocated for the ‘mother tongue’ (native language), while the remainder is free for the acquisition of other (non-native) languages — a conclusion remarkably similar to that drawn by Kim et al. 1997.

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