Spring 2019

The Signing Brain: Its Function, Its Dysfunction, and Its Societal Role

Blaire Marie Pope

THE SIGNING BRAIN: ITS FUNCTION, ITS DYSFUNCTION, AND ITS SOCIETAL ROLE

An Honors Thesis

Presented to

The University Honors Program

Gardner-Webb University

5 April 2019

by

Blaire Pope

Accepted by the Honors Faculty

Prof. Robert Moore, Thesis Advisor	Dr. Tom Jones, Associate Dean, Univ. Honors
Dr. Don Olive, Honors Committee	*Dr. Anna Sieges Beal, Honors Committee*
Prof. Frank Newton, Honors Committee	*Dr. Christopher Nelson, Honors Committee*

Table of Contents

Introduction

This paper is an examination of the signing brain (that is, the internal neurological processes of individuals who use sign language as their main method of communication in their everyday lives) both before and after experiencing neurological trauma, presenting a synthesis of research from lesion studies as well as modern neuroimaging studies. It will be divided into three main sections, followed by a conclusion. The first of these sections will be an introduction to neurology in the most general sense; describing the salient aspects of the brain's anatomy and pointing out where they relate to activities implicated in the use of language, as well as explaining certain neuroimaging techniques described in the studies that are referenced within the body of the paper. The second section will be a discussion of the healthy signing brain and current related topics being researched (both general and sign-specific). The third will be a description of the unhealthy, or dysfunctional, signing brain, viewed through the lens of one particular neurological condition known as aphasia. Finally, the paper will conclude with what can be done with and for signers that are impacted by neurolinguistic communication disorders and present a possible explanation of why there seems to be so few solutions for these individuals, as well as why the resource of sign language studies has been heretofore untapped.

It is perhaps the most important goal of the present work to be accessible to anyone, from a neuroscientific researcher to a layperson. The research put forth by academia can affect great numbers of people, but it is often only academics who can understand it. Thus, it is worthwhile to make a concerted effort towards making formal academic research not only available, but understandable as well. The emphasis of accessibility, achieved in this paper through the deliberate use of clear and readable language whenever possible, will promote a message of inclusivity towards those of all education levels and empower individuals to learn about different parts of the brain and how they each play a role in the neurology of sign languages. It is the hope of the author that this paper may help to show Deaf people how observing their language has contributed to the field of neurolinguistics, as well as encourage them that they are not unintelligent just because they are a linguistic minority.

Specifically, the first part of the paper will focus on presenting neurology in a way that is clearly understandable. To this end, the beginning of the section will be focused on educating the reader in terms of basic neuroanatomy. Key figures in the development of neuroscience, as well as their contributions, will be reviewed. Although the neurolinguistic aspect of the paper will be focusing almost entirely on the cerebrum (the largest distinct area of the brain), it will give a brief overview of other parts of the brain. Discussion will move from broad to detailed, going over general aspects of the brain such as the four cerebral lobes and the cerebellum, and gradually moving towards more specialized and perhaps lesser-known neurological features. This section will also describe the neuroimaging techniques that will be referenced when discussing case studies in the third section.

The second part of the paper will be focused on painting a portrait of the healthy signing brain. Various topics related to current neurolinguistic theory will be discussed, starting with general topics that are relatively new in the literature, such as the mirror neuron theory. Then, the discussion will segue into recent research that pertains more to sign language specifically. These include studies on the hemispheric specialization of the brain insofar as it relates to various activities (also known as lateralization) and how handedness affects brain activity during signing. As well, brain activation patterns in spoken and signed languages will be compared. Importantly, the differentiation between gestures, which are non-linguistic manual signals, and signs, which are linguistic manual signals, will be discussed.

The third section of the paper will home in on the topic of neurolinguistic dysfunction as it presents in Deaf individuals. (A capital D will be used to indicate ‘cultural Deafness’, which refers to participation in the Deaf community and the use of sign language as a preferred method of communication). Particularly, it will focus on aphasia, which is a neurological condition most often caused by traumatic brain injuries (TBIs), many of which originate from cerebrovascular accidents (CVAs, often called strokes). It is characterized most broadly by reduced linguistic production and/or comprehension, although it has many different subtypes which are more nuanced. Aphasia is the subject of choice here, rather than apraxia, because aphasia is not a disorder of the muscles or the result of poor motor planning. Rather, it arises in the brain, often immediately following neurological trauma. Therefore, it is a fitting choice of focus when neurobiology is the topic at hand. The etiology, or different causes, of aphasia, as well as its subtypes, will be named and described, with case studies to illustrate how this disorder presents in the sign behavior of those who are fluent in a signed language. Lastly, the recovery options for Deaf individuals with aphasia will be reviewed and discussed.

In conclusion, the paper will present a sociological explanation as to why there is such a dearth of resources for Deaf individuals who have been impacted by not only aphasia, but communication disorders in general. The perspective that the paper will take is that the pathological view of Deafness, motivated by an underlying attitude of audism, is the single largest contributing factor to the near-complete lack of any sort of treatment for Deaf people with communication disorders. The pathological view of Deafness is the idea that Deafness is merely an audiological problem that needs to be fixed, rather than a valid cultural identity, and generally exhibits a hierarchical view of language, with spoken languages, most commonly English, being superior, and signed languages being inferior.

Cognitive Neuroscience: The Precursor to Neurolinguistics

In an entry for the *Encyclopedia of Neuroscience* entitled "Cognitive Neuroscience: An Overview," C. M. Wessinger and E. Clapham succinctly describe cognitive neuroscience as "understanding how brain enables mind" (1117). This relatively new field of study can be understood as a sort of precursor to neurolinguistics. Surely much can be discovered by studying the brain itself, and indeed it has – but how do those structures specifically give rise to higher-order thinking processes, including abstract ideas and relatively arbitrary systems such as language? This is the question that cognitive neuroscience aims to answer, and it is under the category of cognitive neuroscience that the field of neurolinguistics falls.

Before going forward, though, it is necessary to go back to the basics, understanding the neural substrates that underlie the capacity for higher-order processes. Knowing the history of cognitive neuroscience will help contribute to a fuller understanding of the society in which research up to the present day has taken place. As well, knowing both the anatomy and physiology involved allows for a more comprehensive understanding of the brain as one complete unit, which is influenced by the form it takes on and the system that supports its operation; namely, the nervous system.

Two of the first individuals who attempted to understand the brain holistically were Franz Joseph Gall and J. G. Spurzheim. In the early 1800s, they developed a theory called phrenology. The idea was that the brain was organized around thirty-five distinct functions, ranging widely from color perception to language comprehension (Wessinger and Clapham 1117). Additionally, Gall and Spurzheim believed that when proficiency was gained in a specific area, such as self-esteem, that part of the brain would swell, creating a corresponding bump on the head (1117). Gall and Spurzheim's idea, that the structures of different parts of the brain were related to their functions, was not really that far-fetched. However, phrenology was so widely debunked and discredited that it took quite a while for the idea of a structural-functional relationship within the brain to resurface in the still-young world of neuroscientific research.

The next major discovery that contributed to the study of neurolinguistics occurred in the 1860s. A French neurologist by the name of Paul Broca documented perhaps one of the most widely reviewed case studies. He referred to his subject as 'Tan', because the syllable 'tan' was the only sound that the patient could utter after sustaining severe brain damage. Importantly, Tan could still understand speech perfectly well. When he died, Broca examined his brain, discovering a lesion, or site of damage, on the inferior frontal gyrus, abbreviated as IFG. This spot came to be known as Broca's area (Hopkins 471). This was groundbreaking for both cognitive neuroscience and neurolinguistics. For the first time, a deficit in language was definitively traced back to one specific area, which was later physically observed. Broca's aphasia, characterized by the struggle to produce coherent speech, was named for him. Now, it is often called expressive aphasia or non-fluent aphasia.

A mere thirteen years later, a German neurologist, Carl Wernicke, discovered the exact opposite effect in one of his subjects. This individual could not understand speech at all, instead producing fluent yet nonsensical utterances. In Hopkins' words, "the words kept coming but made no sense" (471). Upon examining the patient's postmortem brain, Wernicke discovered a lesion in a location different from Broca's patient: the superior temporal gyrus, or STG. This part of the brain came to be known as Wernicke's area. Damage to it causes Wernicke's aphasia, now more commonly called fluent or receptive aphasia. It rests a few inches posterior from Broca's (that is to say, farther towards the back of the brain). This seemed to indicate that there was not only one definite location of the brain that was specialized for language. In fact, there were two: one for producing and one for comprehending language.

Although Gall and Spurzheim, Broca, and Wernicke are now retroactively associated with the field of cognitive neuroscience, they did not self-identify as such. The term cognitive neuroscience first came into use in about the 1970s. After this point, neuroscientific researchers who studied how the brain enables the mind were unified under one name and began laying the foundation for the field. Today, it is known as a sort of convergence of different fields, including neurobiology, cognitive science, and psychology. Methodologies from those fields are mixed and matched where appropriate to create an interdisciplinary approach to studying the brain as one complete unit.

Neuroanatomy

One level on which the brain is studied for the purposes of cognitive neuroscience is that of anatomy. Wessinger and Clapham state, "One key avenue in understanding how brain enables mind is grounded in understanding the relationship between brain anatomy and cognition" (1118). The brain does not exist in a vacuum; it is a physical item that takes up space in a specific form, which impacts its abilities and limits. For example, the human skull, while proportionally quite large compared to other animals, is in itself not very big. Thus, the brain is wrinkled in order to fit as much surface area in one small space as possible, as the surface is where much of the electrical activity occurs. Such wrinkling creates folds, known as gyri, and furrows, known as sulci (see Fig. 1). Gyri and sulci affect the way neurons travel within the brain. In this way and in many others, the brain's anatomy (its form) and the brain's physiology (its function) are inextricably linked. It is for this reason that knowing and understanding neuroanatomy is key to unlocking the mysteries of the brain's internal workings.

Part of that understanding comes from knowing that the brain is a part of a larger system: the nervous system. It is the apex of the nervous system, yes; responsible for detecting stimuli and external environmental changes – but it does not operate alone. The brain and the spinal cord together make up the central nervous system (CNS), essentially the information center of the human body. The other half of the nervous system is the peripheral nervous system (PNS). The PNS is comprised of 12 pairs of cranial nerves and 31 pairs of spinal nerves.

Within the peripheral nervous system, there are two kinds of nerves: afferent nerves and efferent nerves. When a stimulus occurs, the afferent nerves collect the sensory information and carry it toward the brain. Then, once the brain has interpreted the stimuli and decided how to proceed, the instructions needed to complete the response are carried by efferent nerves, which then stimulate either muscles or glands to begin the body's response to the stimulus. All of this occurs in milliseconds.

Further dividing the nervous system, the nerves can be halved and classified once again. Visceral nerve fibers, both afferent and efferent, send information to the organs within the body, such as the liver, stomach, pancreas, and many more. Meanwhile, somatic nerve fibers make up sensory and motor nerves that travel to structures closer to the body’s surface, such as skin, skeletal muscles, tendons, and joints. As language is a form of sensory input, the somatic nerve fibers are going to be the key players here.

Mahadevan, in “Neuroanatomy: an overview”, separates the brain into four broad categories: the brain stem, the diencephalon, the cerebellum, and the cerebrum (598). The brain stem, a stalk-shaped structure, is comprised of the pons, the medulla oblongata, and the midbrain. It starts at the base of the neck and extends up into the cranial cavity. Essentially, it acts as a corridor for the sensory information carried by the nerve fibers. The diencephalon, located near the top of the brain stem, sustains the thalamus, which sends sensory information to the cerebral cortex, and the hypothalamus, which regulates unconscious processes such as sleep-wake cycles, balance, and temperature regulation. The cerebellum, located at the back of the skull, is mainly responsible for balance and proprioception (knowing where one’s body is in space, as well as coordination of precise movements). It is incapable of initiating anything; only regulating what has already been initiated (Mahadevan 599).

The most prominent part of the brain is the cerebrum. It is here that the experience of human consciousness takes place. All higher-order brain functions, such as personality, language, abstract thinking, decision-making, and sensory processing occur in the cerebrum. It is divided structurally into two hemispheres. These two hemispheres are made up of a crust of gray matter on the outside. This is referred to as the cerebral cortex (cortex meaning “crust” in Latin). Within each hemisphere is white matter that acts as a conductor for neuronal activity. Finally, there is a cavity called the lateral ventricle, which contains cerebrospinal fluid.

Conventionally, the cerebrum is divided into four lobes: frontal, parietal, occipital, and temporal. The frontal lobe, located at the front of the brain, is quite multifaceted. As it contains the primary motor area, its main job is controlling voluntary movements. However, it also controls decision-making, inhibition, and emotional memory. Importantly, the portion of the frontal lobe in the left hemisphere contains Broca's area, associated with the production of speech. The parietal lobe houses the primary somatosensory cortex, which governs sensory stimuli that are felt on the surface of the body (somatic sensation). The occipital lobe, located at the back of the cerebrum, contains the primary visual cortex and governs processes involving visual perception. Lastly, the temporal lobe contains Wernicke's area, associated with the comprehension of language. It also houses the primary auditory cortex and is associated with linguistic processing and visual memory (Mahadevan 598-599). The regions of the brain associated with language are both near the lateral sulcus, one of the most prominent sulci in the brain. Thus, they are often collectively called the perisylvian region. As aforementioned, the brain is wrinkled to maximize the potential of the space, allowing for more surface area of the cerebral cortex. These create wrinkles and folds known as gyri and sulci (Mahadevan 598). Sulci are also sometimes called fissures if they are particularly deep. While a smooth brain would only be able to grow outward and thus limited in its potential, the presence of gyri and sulci allow the brain to continue growing inward. The folds of the brain affect the way neurons travel. Some of the gyri and sulci of the brain are shown in Figure 1.

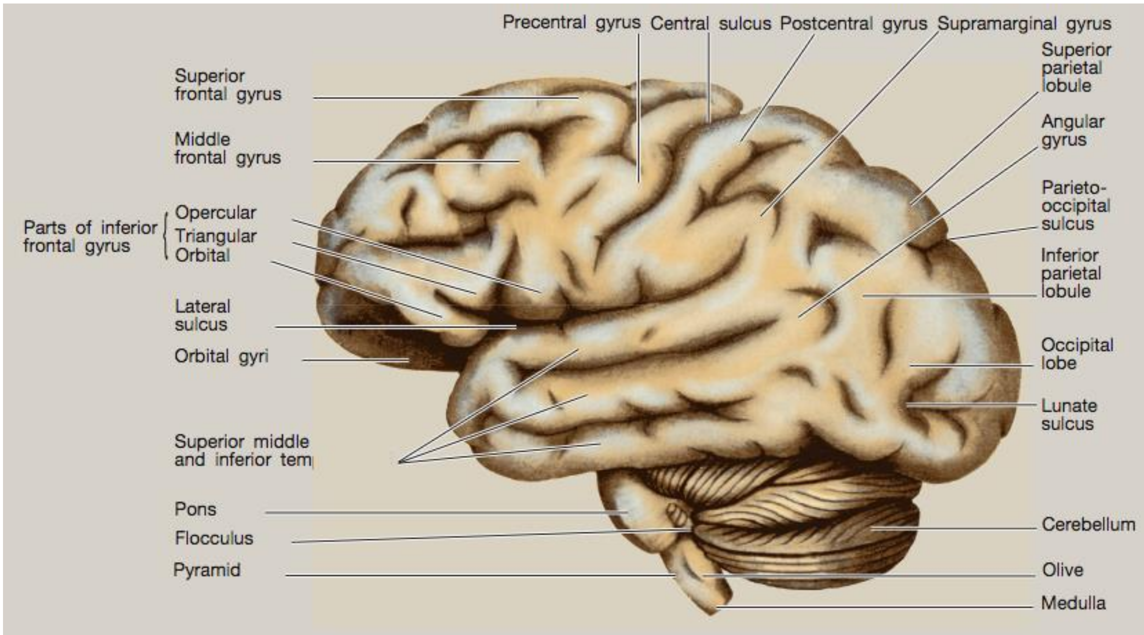

Fig. 1. Lateral aspect of left half of brain showing left cerebral and cerebellar hemispheres and brainstem. Mahadevan, Vishy. "Neuroanatomy: an Overview." Surgery (Oxford), vol. 36, no. 11, 2018, pp. 597–605.

Researchers can observe the brain at an even smaller scale. One of the most famous neuroanatomists was a man by the name of Korbinian Brodmann, a pioneer of cytoarchitecture. Also called cytoarchitectonics, this refers to the study of brain structures as differentiated by their cellular organization. E. G. Jones, in an entry for the *Encyclopedia of Neuroscience*, states, "…structural variation can be seen across the cortex … many of these structural variations can be correlated with distinct patterns of input–output connections, with distinct physiological properties, and often with definable aspects of sensation, perception, cognition, and motor control" (477). Cytoarchitectonics is important because in the same way that gyri and sulci affect the brain on a gross anatomical level, cell structure affects it on a microanatomical level. In 1909, Brodmann divided the cerebral cortex into fifty distinct numbered areas. The map he created is still used today. Neuroscientists refer to Brodmann areas by their corresponding numbers, i.e. BA 44. With the advent of more sophisticated technologies, Brodmann's original map has been refined. Wessinger and Clapham estimate 30 different cytoarchitectonic structures in the visual system alone (1117).

Michael Petrides, in *Neuroanatomy of the Language Regions of the Brain*, describes the cytoarchitecture of the cerebral cortex. He likens it to "an enormous sheet" of gray matter, consisting of neurons and glial cells (90). However, this enormous sheet is not entirely the same across the brain. There are various types of cell structures within the cerebral cortex, and the diversity of those cell structures allows the brain to do more things. Much in the same way that the wrinkling of the brain maximizes its growth, the many varieties of cytoarchitectonic structures maximize the brain's potential. This is yet another way that anatomy relates to physiology. Petrides notes, "[the structures] are relevant to understanding the neural basis of language, because all cognitive processing is nothing more than the complex functional interactions between networks of cortical and subcortical areas" (90).

How are these cell structures differentiated, and how are those differences realized? According to Zilles et al., "A single criterion is rarely enough to define the borders of a cytoarchitectonic area" (115). Instead, there are a few criteria, based on morphological aspects of the brain, that help to determine the cellular structures that exist in the cerebral cortex. These include the number of cortical layers as well as their visibility (i.e. how well they can be distinguished from each other), the size and the density of the layers, the presence and proportion of general or highly specialized cells, the thickness of the cortical ribbon, and the width of each layer when compared to other layers (115).

Cytoarchitectonically, the brain can be divided into two general regions: the isocortex and the allocortex. The isocortex is the largest part of the cerebral cortex and contains six distinct layers. Beginning with the outermost layer closest to the skull, Layer I, also called the molecular layer, is relatively sparse when it comes to cell bodies. It consists mostly of neuroglial cells and non-pyramidal neurons. Layer II is comprised of very small pyramidal neurons, giving it a grainy appearance, hence its name: the external granular layer. Layer III, the external pyramidal layer, is a “broad layer of pyramidal neurons” (Petrides 91). This layer is divided into three parts, IIIa, IIIb, and IIIc. Layer IV, or the internal granular layer, is a dense layer comprised of small neurons, much like the second layer. Layer V, or the internal pyramidal layer, contains a less dense structure with sparsely placed pyramidal neurons. Finally, Layer VI, called the multiform or polymorph layer, consists of modified pyramidal neurons that are very densely packed (Petrides 92).

Meanwhile, the allocortex has only three or four layers and is definitively a smaller portion of the cerebral cortex. It is comprised of the paleocortex and archicortex. The former of these contain the olfactory bulb, retrobulbar region, and the olfactory tubercule. Because it is so connected to olfactory sensing, or the function of smell, it is also called the rhinencephalon. The archicortex contains the hippocampal formation (the hippocampus is related to the storage and encoding of information from short-term into long-term memory). The area between the isocortex and the allocortex is called the periallocortex (Petrides 94).

How do these structures work together to provide the brain with information? Neurons, the tree-like cells of the nervous system, are the most important unit of communication within the brain. Mahadevan describes them as the “structural and functional unit[s] of the nervous system” (597). The dendrites on one end receive messages and carry them towards the cell body, while the protruding axons on the other end send and carry them away from the cell body. The electrical impulses, when they reach the end of the axon, jump across a gap called a synapse in order to reach the next neuron. Neuronal communication is the basis for all neurological processes, and it is by studying patterns of such communication that researchers can map the localization of brain functions and how they relate to bodily functions.

Neuroscientific Research

In the past, it was impossible to observe the brain while it was actively functioning. Essentially the only methods of studying the brain were through behavioral observations, or what are called lesion studies. This typically involved a researcher observing one subject that had sustained a traumatic brain injury (usually either a stroke or a head trauma due to some sort of accident), inferring the location of the lesion based on which behaviors were impaired, and then, if possible, examining the postmortem brain to determine if the hypothesis was correct.

Perhaps the most famous example of the lesion inference method is that of Phineas Gage, who, in 1848, accidentally drove an iron spike through his frontal lobe and, shockingly, survived. Post-injury, his bodily functions were completely intact – the only affected part of him was his personality. He became aggressive, angry, and violent. In fact, his friends referred to him as being “no longer Gage”. It took decades for Gage’s anger to subside, although he did somewhat return eventually to his pre-injury personality. From this, researchers inferred that the frontal lobe, which sustained the most damage from the spike, is where personality centers are located.

This method may seem fine at face value, but it can be problematic. Despite the efforts of researchers to compartmentalize the brain into neat categories, it is far more complicated than a mere structural-functional relationship. The traumatized brain does not act the same as the non-traumatized brain. Although only one area of the brain may have a detectable lesion, the entire brain is affected by injury. Additionally, cortical plasticity allows the brain to adapt to the damage. While all brains share universal qualities, the ways that different people's brains adapt to trauma can be quite idiosyncratic, meaning that the lesion inference method is not infallible. However, with recent technological advances, scientists can look in on the brain while it is still healthily functioning, without having to wait for someone to get injured so that a case study can be done. Two of the most common neuroimaging techniques used for neuroscientific research are functional magnetic resonance imagery (fMRI) and electroencephalography (EEG).

Cheryl Capek and Helen Neville, in *Research Methods in Sign Language Studies,* discuss these specific neuroimaging techniques because they are typically employed in studies of the brains of signing people. These ways of observing the brain lend themselves well to studying neural connections as well as neural organization of cognitive functions, which are essential to understanding the brain's interaction with language (322). Some of these methods are used in the case studies that will be discussed later.

The first and perhaps most popular way of looking at the brain as it functions is magnetic resonance imaging, or MRI. First, hydrogen atoms in the body are all aligned parallel to each other by the magnetic field of the MRI machine. Then, the hydrogen atoms are “briefly perturbed” (Capek and Neville 322) by a fast radio pulse. Then, the rotation of the nuclei as they return to their original state is measured by instruments called receiver coils. The density of the tissue affects the amount of time that the nuclei take to return to the original state of alignment, with denser tissue taking longer to realign. The software in the machine processes differences in the amount of realignment time required. Thus, MRI produces “exceptionally clear delineation of different tissue types” (Capek and Neville 322).

While typical MRI only shows a static image, functional MRI, abbreviated as fMRI, uses a series of composite images to map the activity in the brain by measuring blood flow. Two important proteins in the blood, oxyhemoglobin and deoxyhemoglobin (which are oxygenated and deoxygenated versions of the same protein), have different signal intensities. Neurons that manage more demanding or higher-order tasks will require more oxygen-rich blood in order to create enough energy to complete the tasks. The measuring of the differences in oxygenated blood levels in the brain is what makes up functional magnetic resonance imaging. These are known as blood oxygenation-level-dependent (or BOLD) effects. By watching where the oxygen-rich blood travels in the brain, neural activity can be inferred. Although they are not fast (peaking at 6-10 seconds after the onset of a stimulus), they are spatially accurate, with the margin of error being only millimeters (Capek and Neville 325).

Capek states that the main challenge of fMRI is to “detect a small, experimentally induced response embedded in noise” (322). The word “noise” here does not refer to auditory stimuli, but rather any stimuli that would cause extra neuronal activity, making the scan less clear. This can be generated by the participant, the machine, or even the environment. Neuronal activity is sometimes difficult to track using fMRI, as it is such a relatively small blip compared to everything else happening inside and outside the participant's body. Any distraction from the outside world could cause the participant's mind to stray from the task at hand.

A control is a condition in an experiment that stays the same for all participants. It is also sometimes referred to as a baseline task, and it sets the standard for the experimental task to be compared to when analyzing the results. Selecting appropriate control conditions for sign language during an fMRI study can be challenging. Muscle movement in general is a task that requires much oxygen-rich blood – so the neural activity of linguistic processing in the brain can sometimes be drowned out, so to speak, by the neural activity of moving the hands to sign. Movement of the hands also creates noise, which can interfere with the results of the fMRI scans. Signers participating in fMRI-based experiments are usually instructed to keep their signing at a "whisper" level and try to only use one hand to articulate their responses to questions or tasks, which can impact their legibility (Capek and Neville 325).

Another challenge of fMRI-based studies involving signers is the need to look in different directions. Eye gaze, a crucial part of visual processing for sign language, can create noise and disrupt the images created by the machine. Due to the potential for noise, Capek recommends no communication at all during fMRI studies during the scans themselves. With hearing participants, they may wear a microphone and headset that they can communicate through, but d/Deaf participants do not have access to this way of speaking during the experiment. Instead, MR-compatible cameras can be set up so that the d/Deaf participant can see the signed questions, but this is not always an option (Capek and Neville 327).

Another oft-used neuroimaging technique is known as electroencephalography, or EEG. This approach to viewing brain activity takes an electrical route. Messages in the brain are passed along via electrical and chemical signals. The electric impulse, also called an action potential, moves along a part of a neuron called the axon. When it reaches the end, the electric signal is converted to a chemical signal, which stimulates the neuron next to it. The gap between the neurons is called a synapse. Electroencephalography uses electrodes on the scalp to measure the change in electricity that is caused when neurotransmitters bind to the cell membranes on the other side of the synapse (Capek and Neville 324). Continuous EEG measurements are divided into sections of time called epochs, marked by the start of a particular stimulus or task (325). This is known as event-related potential.

While fMRI provides wonderful spatial resolution but poor temporal resolution, EEG is the opposite. It measures neural activity directly, rather than inferring based on blood flow. However, the skull can diffuse the electrical activity, distorting the results. Electrodes are placed according to the 10-20 system, an internationally used method of electrode placement. Despite this, what Capek describes as the "idiosyncratic folds" (325) of the cortex can still affect the accuracy of the results; no standardized method of electrode placement can be fully customized to match the specific folds in each person's brain. Although the folds are the same, their positioning within each person's skull will be different (Capek and Neville 325).

In order to maximize success during EEG-based sign language studies, the onset of each stimulus must be carefully specified. Capek notes that in studies of spoken language, it is possible for the beginning of a word to be "obscured by extraneous acoustic information" (325). The same phenomenon can occur during studies of sign language processing. It is crucial that the beginning and end of the sign is clearly marked. As well, the group of participants should be as similar as possible, grouped by hearing status and age of language acquisition. These are the factors most likely to introduce inhomogeneity, or dissimilarity, in the results. As with fMRI studies, cameras may need to be set up so that the participant and the researcher (most likely speaking through an interpreter) can communicate. During the actual testing process, communication between the two parties should be avoided if at all possible. Certain movements can contaminate the signal, especially if the electrodes are physically disturbed. Signers are advised not to use signs that touch the face and head. This can present a problem for EEG-based sign language studies, as it is rather impractical to ask signers to avoid an entire group of sign locations.

Neurolinguistics

It has been demonstrated that the brain's anatomy affects its physiology. It has also been determined that there are specific ways that the brain relates to language, on both a cytoarchitectonic level and a more gross anatomical level. Additionally, specific ways that researchers look at the brain have been delineated. The topic at hand has now shifted from structure to function, and thus requires a redirection to the main question: is the signing brain functionally different from the speaking brain?

Physically, the answer is no. Using magnetic resonance imaging, researchers can look at the structure of the brain and detect the amounts of white and gray matter within the cerebrum. As of now, research shows that structurally, Deaf and hearing brains are entirely similar, with the differences being idiosyncratic (no two brains are exactly alike). There is no indication that regions that support auditory processing are of smaller volume in Deaf people. There is even some research that indicates that in the absence of auditory input, the auditory cortex can be recruited by the brain to assist in visual processing. However, Campbell notes that "subtle differences are apparent", describing one report that suggests different patterns of connectivity between white matter in Deaf and hearing people. This report also found thicker connections between perisylvian and auditory regions in hearing people (9). This is unsurprising as hearing people strengthen those connections by hearing language – something that Deaf people do not do.

Although the physical layout of the brain is almost the same among Deaf and hearing people, there are similarities and differences between the way sign language and spoken language interact with the brain. This is often explored in studies of signing and speaking bilinguals. Söderfelt et al. contrasted Swedish Sign Language and spoken Swedish, first in 1994 and again in 1997, using positron emission tomography (PET). The 1994 study found no significant differences, but the 1997 study, which used more complex methods, found differences "as a function of language modality" (Campbell 10), meaning that the differences were a function of speaking versus signing.

Activation differences were not found in perisylvian language regions. Instead, they took place in the regions that are specialized for different input modalities (Campbell 10). The auditory cortex, located in the superior temporal lobe, was activated more by spoken language. Conversely, the visual cortex, located in the posterior inferior temporal lobe as well as regions in the occipital lobe, showed more activation as a result of viewing Swedish Sign Language.

These results cannot be taken at face value. Helen Neville, in a 1998 study, discovered that reading English and watching ASL both activated classical left-hemispheric language regions. However, there was also extensive activation in the right hemisphere, including the right perisylvian regions (Campbell 11). Neville argued that the right-hemispheric involvement was caused by the increased spatial processing demands of signed languages. Additionally, signed language processing in native ASL signers appeared to recruit the right hemisphere to a greater extent than written language processing in hearing nonsigners – which does not fit at all with the data from the lesion studies.

Neville's study was highly criticized by her contemporaries because it compared written English to signed ASL, rather than spoken English to signed ASL. The English sentences were shown one word at a time, "lacking the intonation, stress, or other prosodic features typical of face-to-face communication" (Campbell 11). In contrast, the ASL sentences were presented naturally, with all discoursal and paralinguistic aspects intact. Written English and signed ASL is a false equivalence, meaning that while Neville's study was not entirely problematic and did have useful findings, it did not reach its full potential.

In order to build upon Neville's study, Mairead MacSweeney et al. conducted a study in 2002. It compared British Sign Language (BSL), presented visually to Deaf native signers, with spoken and written English presented to hearing nonsigners. The perception of BSL and English were found to recruit very similar neural systems, including the classical perisylvian regions. Surprisingly, MacSweeney's study found right-hemispheric activation in the comprehension of both languages, with no difference as a function of modality. Of this, Campbell states, "Taken together, this suggests that many of the differences between spoken and signed language patterns of activation reflect the modality-specific processing requirements of the perceptual task, rather than the linguistic aspects of it" (12). Daphne Bavelier, a contributor to Neville's 1998 study, described this phenomenon as "left invariance, right variability" (qtd. in Campbell 11). This means that although the levels of activation in the right hemisphere may ebb and flow, activation in the left hemisphere is consistent.

Campbell agrees with Bavelier's "left invariance, right variability" concept, but goes a step further by positing a question: why is there right variability? She notes that the types of tasks performed in the study may have an impact on the results – Neville's task was one of memory, whereas MacSweeney chose an anomalous sentence detection task. Potentially of greater importance, though, is the level of bilingualism present. Bilinguals are a special case in studies of neurolinguistics, because the age of second language acquisition has been shown to play a role in patterns of brain activation and language. A sign-specific caveat to this is that hearing signers (even those that sign natively) still have access to the auditory modality, whereas deaf native signers do not. Campbell suggests that the answer may be as simple as a task discrepancy or as complex as a "theoretical difference between the languages or populations tested" (13).

In 2001, Cheryl Capek and colleagues did a study in which they showed Deaf native signers ASL sentences that contained a syntactically wrong verb – meaning, the verb was reversed in direction (directionality of a sign refers to its movement and this establishes subject-verb agreement in sign languages). Using neuroimaging techniques, they were able to determine an early anterior negativity that was larger over the left hemisphere. Essentially, this means that the brain's processing of the error was localized to the left hemisphere, reflecting findings in studies of hearing people. When a syntactic error is encountered, it is processed in the left hemisphere as well. Campbell notes, "[I]t seems that the type of syntactic element being processed … can affect the electrophysiological trace … This is a good example of how research on signed language can generate hypotheses for spoken language and not only vice versa" (9).

One idea that has been proposed to explain the interplay between language and the brain is the mirror neuron theory, popularized by neurophysiologists in the late 1980s when researchers observed patterns of activation in a certain area of the brain in macaque monkeys. The homologue in the human brain happens to be Broca's area. Mirror neurons are neurons in the brain that are activated both when performing an action and observing an action. They were observed in the monkeys when they watched an object being grasped as well as when they grasped that object themselves. The mirror neuron theory supports the embodied theory of language comprehension, which claims that the body and the mind work together to understand language. According to the theory, different parts of the brain related to semantic, motor, and auditory processing will all activate upon hearing language – for example, hearing the word "swim" would evoke neuronal activity in Broca's area, Wernicke's area, and the precentral gyrus, where the primary motor cortex is located.

Because it is impossible to study the activation patterns of one single neuron, all information currently known about mirror neurons is speculative. A human analog of the macaque monkeys' mirror neuron system could be the neural substrate for all sorts of higher-order functions, including empathy, learning, and intention. If what is known about the mirror neuron system is to be believed, it would have groundbreaking implications for the study of the brain and language. Some have even pointed to the mirror neuron theory as a possible explanation for the origin of language (Knapp and Corina 36). Heather Knapp notes that signed languages are natural candidates for study through the schema of the mirror neuron system, because they "possess all the linguistic complexity of spoken languages but are perceived visually and produced manually" (36).

Studies that are neurolinguistically motivated may benefit from choosing to observe sign language rather than spoken language. In 2016, Kayoko Okada and several colleagues (including David Corina and Gregory Hickok, both prominent neurolinguistics researchers who often use sign language in their studies) performed a study with Deaf native signers to see if a connection could be made between sign language and mirror neurons. Of particular interest was receptive speech function. If the mirror neuron system activates both when observing speech and producing it, and Broca's area in humans is responsible for language production, it could then be concluded that Broca's area would be implicated in both production and comprehension of sign language, since the human mirror neuron system is in Broca's area.

The study used fMRI to measure BOLD changes when Deaf signers viewed a video clip of an action involving an object. Immediately following that, they either generated a sign naming the action, generated a sign naming the object, viewed a sign that named the action, or viewed a sign that named the object (180). They reported that viewing and generating signs activated different areas, that Broca's area was activated during both visual and motor conditions, and that action-related signs (i.e. those based on gestures) did not yield more activation in motor-related regions. In a study of sign language, this is especially interesting, because sign language is a motor-based language. To find that the motor system has a tenuous-at-best connection to the semantic processing of sign, despite the entire language being predicated on the fine motor cortex, certainly has some negative implications for the mirror neuron theory. It was the use of sign language in the study that made this difference ever more prevalent.

Corina and Knapp predict three properties that a mirror neuron-based language schema would have to maintain in order to be logically sound: that damage to the system should disrupt both sign language and non-linguistic action processing, that any singular mirror neuron should mediate both perception and production, and that the individual neurons should support the highly intricate "vocabulary of action" (Corina and Knapp 36) for signed languages. After reviewing data from the literatures of both the mirror neuron theory and signed languages, the authors conclude that their predictions are only partially fulfilled.

If the mirror neuron system is indeed the basis for human language, as much of pop psychology seems to believe, any impairment of such a system would necessarily implicate both signs and gestures. The authors' research is dissonant from this claim. He says, "…if [language and gesture] share a core neural system for perceptual-motor matching, sign and gesture should rarely functionally dissociate in instances of mirror neuron system damage" (37). Corina (1992) reports an adult patient named W.L., who demonstrated ASL production and comprehension impairment after a left-hemispheric lesion, but "retained intact pantomime comprehension and production, using gestures to convey symbolic information that he ordinarily would have imparted with sign language" (Corina qtd. in Knapp and Corina 37). Metz-Lutz et al. (1999) report a case of a child who acquired aphasia after a temporal-lobe epileptic seizure. The authors describe him as being unable to learn French Sign Language, but "unimpaired on ideomotor and visuospatial tasks and produced unencumbered non-linguistic pantomime" (37). Because aphasia spares gesture and impairs sign, it seems implausible that the mirror neuron theory is a reliable basis for understanding the brain's relationship to language. Embodied theories of language cognition do not stand up to criticism, and when viewed through the lens of sign language, the disparities become even more prominent.

Certain features of sign language do not exist in spoken language, and vice versa. Additionally, because sign language is an entirely different modality of communication than spoken language, paradigms for spoken language research are not always conducive to effective results with studies of sign language. It is impossible to simply transpose spoken language research methods onto sign language. Therefore, any conclusion about the signing brain must first be inventoried with the assumptions that underlie it and the methods that were used to reach the conclusion.

One example of this is the use of facial expressions in sign language. In a 1999 study of facial expressions in signers, Corina describes two types: affective and linguistic. Affective facial expressions are used to convey an emotion and are considered paralinguistic features. If an utterance is incorrectly matched with a facial expression (i.e. someone smiling while saying something sad), it may appear strange, but the linguistic utterance still holds its original meaning. Conversely, linguistic facial expressions are embedded in the grammaticality of a sentence. The incorrect production of a linguistic facial expression changes the meaning of the utterance (Corina, *Neuropsychological Studies* 320).

In Corina's study, he examined how linguistic facial expressions were affected in left- and right-brain lesioned signers. He found that right brain-lesioned patients were missing affective facial expressions but preserved linguistic facial expressions. The reverse is true for left brain-lesioned patients. In one case, a subject named Gail D. used too much affective facial expression, appearing almost cartoonish. Corina speculates that this may have been "a compensatory device for her linguistic deficits in ASL" (*Neuropsychological Studies* 320).

What Corina calls a “double dissociation” (*Neuropsychological Studies* 320) between production of affective and linguistic facial expressions indicates that these findings cannot merely be attributed to impairment of the facial musculature, since one and the same muscular system is used for both types of expressions.

Another unique element of sign language is its asymmetry. This generates questions about the relationship of handedness to the brain-language connection. In spoken language, articulation of speech is carried out by the mouth: a structure that is located on the midline of the body and is the same on both sides. The mouth’s articulatory movements are rarely, if ever, asymmetrical. In sharp contrast, the articulators of sign language, which are the upper limbs and hands, “produce a variety of both symmetrical and asymmetrical configurations, at times moving with a fair degree of independence” (Corina, *Language Lateralization* 718). This is unique for two reasons: the first being the presence of two articulators instead of one, and the second being the lateralization of said articulators. This is yet another aspect of sign language that can provide unique information about the intersection of brain and language.

Because each side of the brain governs the opposite side of the body, one might assume that the right-handedness of most signers would contribute to the strongly left-lateralized activation during the production of sign language. The dominant hand, which is usually also one’s dominant hand for nonlinguistic tasks, “exhibits a far greater range of handshapes and places of articulation than that of the nondominant hand” (Battison qtd. in Corina, *Language Lateralization* 718). During instances where one’s preferred hand is occupied, signers can easily adapt to signing with only one hand, even if it is their nondominant hand (the spoken language equivalent of this would be talking with one’s mouth full of food). Corina says that studying sign language provides an opportunity to evaluate the "mutability of the neural representation of language in the face of contrasting articulatory task demands" (*Language Lateralization* 718).

Corina and colleagues' study "Language Lateralization in a Bimanual Language" used positron emission tomography (PET) to examine brain activation in sixteen deaf American Sign Language users. All sixteen subjects were right-handed, and profoundly deaf from birth. Ten females and six males participated. All sixteen subjects were "highly fluent" (Corina, *Language Lateralization* 727) in ASL and preferred to use it as their everyday method of communication. The stimuli consisted of one male deaf actor producing forty-one one-handed signs for common nouns. After that, subjects engaged in one of several task conditions: repeating each noun using the right or left hand, or generating a verb selected to match each noun with the right or left hand.

Corina says, "Generating verbs with either the right hand or left hand alone produced conspicuously similar activation patterns" (*Language Lateralization* 719). His observation of the unilateral activation is described on page 719:

> Conjunctions – or common patterns of activation for right- and left-handed tasks – were observed in the dorsal (BA 44/45) and ventral (BA 47) portions of the frontal operculum, the anterior insula, the inferior (BA 46) and superior (BA 9) portions of the dorsolateral prefrontal cortex, and the fusiform gyrus (BA 37).

Corina describes the bilateral activation patterns in the same section, saying, "Conjunctions were detected in the right cerebellar hemisphere and midline cerebellum, the left caudate nucleus, left midbrain PAG, and the dorsomedial thalamus bilaterally" (*Language Lateralization* 719). Essentially, Corina et al. found that left-handed signing was associated with greater activation in the left parietal lobule (which, curiously, corresponds to

Wernicke's area – classically only associated with comprehension) and was more unilateral, whereas right-handed signing carried a stronger correlation with sensorimotor areas of the brain.

With right-handed signing, the patterns of activation were more bilateral. This finding is surprising considering that typically, use of the dominant hand "yields a robust and marked asymmetrical activation in contralateral primary motor regions, while nondominant hand use yields less robust and less strongly asymmetrical activation in the primary motor cortices" (Dassonville et al. qtd. in Corina 726). It may be the case that because most signs are articulated with both hands, the suppression of the left, or nondominant, hand in order to only use the dominant right hand contributes to increased sensorimotor activity in the brain. Additionally, the nondominant hand often serves as a "base" for the dominant hand to act upon. The absence of the base essentially takes away half of the sign, which may result in more emphatic signing (leading to increased activity) as the brain compensates for half of the sign being missing.

Meanwhile, left-handed signing led to a more unilateral activation pattern. Left parietal regions are specialized for executing complex motor behaviors, especially what Corina calls "sequential and possibly phonological movements" (*Language Lateralization* 726). He notes that it is likely that the left parietal regions are more activated by this process simply because it takes more effort to sign with one's nondominant hand.

Corina's study concluded that nearly identical patterns of left-hemispheric activity are shown when deaf signers generate verbs independently with both their dominant and nondominant hands. This is consistent with prior research and points toward a strongly left-lateralized neural network for signed languages, even regardless of dominant handedness.

Additionally, the patterns of activation observed were more consistent with studies of linguistic processing than studies of action understanding and execution (*Language Lateralization* 727). These findings further cement the theory that sign language interacts with the brain like a spoken language instead of like a gesture.

That finding, however, raises another question: what exactly are signs, and how are they different from gestures? Mairead MacSweeney and colleagues attempted to find the answer to this question by conducting a study entitled "Dissociating linguistic and nonlinguistic gestural communication in the brain." In this fascinating study, Deaf, hearing signers, and hearing nonsigners viewed visual materials containing both British Sign Language and Tic Tac, a manual code used by bookmakers to communicate the odds in horse races.

Why Tic Tac? MacSweeney describes it as lacking the phonological structure of BSL, but still having similarity in terms of its visual and articulatory components (*Dissociating* 1605). Tic Tac sequences make use of hand configurations and patterns of hand movement. As well, they have the gestural and rhythmic qualities of signed languages. MacSweeney adds, "… the comparison of Tic Tac and BSL has the power to distinguish cortical regions associated with language processing from those associated with its nonlinguistic (or prelinguistic) characteristics" (*Dissociating* 1606). The choice to compare two different manual codes, one linguistic and one nonlinguistic, provides an equal playing field to tease out the similarities and differences between how the brain understands both.

The two goals of the study were to find the "cortical circuitry" (*Dissociating* 1605) associated with linguistic and nonlinguistic manual movements, as well as discover how much the auditory cortex can be activated by visual input. The regions of the brain that contain the auditory cortex have shown to be similar in Deaf and hearing people. The regions, as listed by MacSweeney on page 1606, include Heschl's gyrus, located within the sylvian fissure, the superior temporal gyrus (including Wernicke's area), and the planum temporale, which lies posterior to Heschl's gyrus on the superior temporal plane. These regions have to do with the processing of complex sounds in hearing people, but in the absence of auditory input, they may be recruited for the processing of complex visual stimuli.

Several studies have conflicted on this matter, with Petitto et al. (2000) reporting that superior temporal regions are specialized for analysis of phonologically structured material no matter the modality, and Finney et al. (2001) reporting that patterns of dot movement can activate these auditory processing regions in the brains of Deaf people (MacSweeney et al., *Dissociating* 1607). In order to reconcile these findings, MacSweeney proposes that the superior temporal cortex, including Heschl's gyrus and the planum temporale, may be involved in processing "dynamically patterned visual stimuli" (*Dissociating* 1606) but that the addition of phonologically structured information may increase the activation in these areas, as processing linguistic movement is a more neurologically demanding task than processing nonlinguistic movement.

In this study, eighteen right-handed signing participants were tested. All subjects were native signers and acquired BSL from Deaf parents as their first language. Nine were congenitally profoundly deaf from birth, and nine were hearing. All had good English-language skills and six of the native signers were BSL interpreters by trade. On a test of British Sign Language perception, there was no significant difference. As a control group, eight hearing nonsigners were tested. No participants had any prior knowledge of Tic Tac, and the group was similar in terms of education level, with most having completed tertiary education (MacSweeney et al. *Dissociating* 1607).

The stimuli involved a continuous silent video of a Deaf native signer who performed both the BSL and the Tic Tac stimuli. Being comprised of four to six distinct signs, the BSL sentences were short declarative sentences, lasting about three seconds. The BSL model learned several Tic Tac gestures and then combined them into a “sentence” of sorts, comprised of three or four signaled odds. They were also instructed to add facial gestures to appear more like British Sign Language (MacSweeney et al. *Dissociating* 1608).

In the first experimental condition, participants viewed five BSL sentences, one of which contained semantic anomalies (the example used in the study was “The mug fell off the dream” [MacSweeney et al., *Dissociating* 1608]). The hearing nonsigners were instructed to guess which sentence was nonsensical. The second experimental condition involved participants viewing five Tic Tac “sentences”, with the same anomalous detection task being presented after the viewing of the sentences (MacSweeney et al., *Dissociating* 1608). The mean percentage of anomalous BSL sentences correctly identified was 80%, with hearing signers correctly identifying 60%. Unsurprisingly, the performance of hearing nonsigners was poor – however, they did perform above chance, identifying 35% of the anomalous sentences. In order to keep the participants paying attention, the nonsensical sentence was always the third, fourth, or fifth option.

Among every group, even the hearing nonsigners, an “extensive frontal-posterior temporal network” (MacSweeney et al., *Dissociating* 1610) was activated. This included the planum temporale. In Deaf native signers, the activation was bilateral, although their patterns of activation were more strongly left-lateralized for Tic Tac and right-lateralized for BSL. In hearing native signers, the patterns of activation were very alike, showing bilateral activation in both frontal and posterior temporal cortices as well as in the left planum temporale. The temporal activation extended into the supramarginal gyrus in the left hemisphere, but not the right. In hearing nonsigners, the networks activated were surprisingly similar, with extensive bilateral posterior inferior and middle temporal activation extending through the superior temporal gyrus. MacSweeney notes in her summary that “there is a very high degree of similarity between the systems supporting BSL and Tic Tac perception regardless of BSL knowledge or hearing status” (*Dissociating* 1610).

The planum temporale was activated in all three groups. This is highly surprising since this area of the brain has classically only been thought of as an auditory processing region. It could be assumed that with the absence of auditory input, the planum temporale could be recruited as a visual processing tool. If this were the case, planum temporale activation would not be seen in hearing signers or nonsigners – but it showed strong patterns of activation in all three groups.

Although there were striking patterns of similarity observed in the three groups, there were also some notable differences. For instance, in both signing groups, activation was more extensive for BSL than Tic Tac, and the differential activations were “predominantly left-lateralized” (MacSweeney et al., *Dissociating* 1611). The Deaf group specifically showed more activation in the posterior temporal lobe to the supramarginal gyrus. The hearing group showed a very similar pattern – however, their activation did not extend to the supramarginal gyrus as the Deaf group’s did. Both signing groups showed limited regions of activation for Tic Tac, which was focused in the right hemisphere in posterior inferior temporal and occipital regions (MacSweeney et al., *Dissociating* 1611).

The hearing nonsigners showed the most differentiation. While BSL and Tic Tac showed different activation patterns, the hearing nonsigners' BSL activation regions were focused mainly in the occipital lobe, which indicates visual processing. They showed much more activation in response to Tic Tac than to BSL. Their activation when viewing Tic Tac involved Broca's area (BA 44), the precentral gyrus (BA 4), and the anterior cingulate, which is related to memory and learning. Regarding this, MacSweeney et al. says, "When sign language is understood, specific processing demands are made on the left posterior perisylvian cortex" (*Dissociating* 1612).

MacSweeney et al.'s study concluded that the patterns of brain activation for sign and gesture are different neurologically. Specific patterns of activation were observed in Deaf and hearing signers when viewing British Sign Language. They both showed activation in the left posterior perisylvian regions (Wernicke's area). Studies of hearing English users have found that the left posterior superior temporal sulcus is employed when comprehending phonetic sequences (Wise qtd. in MacSweeney, *Dissociating* 1614). The findings here suggest that it plays the same role in signers.

One of the most interesting findings is that only Deaf signers showed patterns of activation in the left supramarginal gyrus. MacSweeney says that this region has been implicated as a key site for processing sign language phonology (*Dissociating* 1614). It shows greater activation during processing of signs than for fingerspelling (Emmorey qtd. in MacSweeney, *Dissociating* 1614). Bilateral activation was also observed in Deaf individuals, with Broca's area as well as its right-hemisphere equivalent showing activation in the MRI scans. These are consistent with data found in other studies, implicating the SMG as a crucial area for sign language processing.

The signing brain has been shown to produce the same patterns of activation as the speaking brain. While several theories have been developed to explain this, one being the mirror neuron theory, researchers have yet to find a concrete explanation. Often, a theory is developed, but it may only apply to spoken language and not sign language. The study of sign language generates new ideas within the field of linguistics, making it an important research tool. Additionally, gesture and sign interact differently with the brain, as seen in MacSweeney's study. Key areas associated with sign language production and comprehension are the supramarginal gyrus (Wernicke's area), and the inferior frontal cortex (Broca's area, historically only associated with language production). More research is needed to determine why this is the case.

Linguistic Dysfunction: Aphasia

Observing the brain in its functioning state is important in order to gather more information about how it works. However, lesion studies also provide key results in understanding how the brain works with language. The main language areas in the brain, classically called Broca's and Wernicke's areas but now often referred to by their clinical labels, when impacted by traumatic brain injuries (TBIs), cause a condition called aphasia in Deaf people as well as hearing people. Corina notes, "Linguistic breakdown after left hemisphere damage is not haphazard, but it affects independently motivated linguistic categories" (Corina, *Processsing* 433).

Aphasia is a type of neurological dysfunction that affects Broca's and Wernicke's areas. From studies of both signed and spoken language aphasia, researchers can infer that users of ASL, despite using motor movements and not oral utterances, are affected by aphasia in the same way that users of spoken language are, implying that both visual-gestural and auditory-spoken languages are associated with activation patterns in the same area of the brain. However, as sign systems and spoken systems are different, the identification and classification of aphasia in Deaf individuals can be difficult due to the possible comorbid presence of apraxia, especially after stroke.

Apraxia is the muscular inability to form the correct mouth positions necessary to speak correctly. Aphasia and apraxia are difficult to delineate in general, but they can become seemingly inextricable when sign language is added into the mix. How is it possible to determine if the problem is neurological or muscular if the language itself depends on the movement of muscles? David Corina notes the presence of linguistic register in sign language and the tendency of sign language users to reduce two-handed signs to one-handed signs in more informal situations, and says, “we are confident that sign aphasia is not due to motoric factors when, for example … sign formation errors appear on the nonhemiplegic [not paralyzed] hand” (320).

Aphasia resides entirely in the brain, and like many other neurological conditions, it has a variety of strains. In addition to Broca’s and Wernicke’s, there are several other types of aphasia. Global aphasia is the most profoundly affective type. Individuals with global aphasia are entirely functionally illiterate; unable to read or write at all. Mixed non-fluent aphasia is like a very severe form of Broca’s; however, people with this form of aphasia typically never recover enough to read or write beyond an elementary school level. Anomic aphasia is usually considered a subtype of Broca’s and can present in individuals with less profound trauma. It is characterized by the inability to find words – for these people, words are always “on the tip of their tongue”. Finally, the last type is known as primary progressive aphasia (PPA). This type of aphasia results from the progressive deterioration of the areas of the brain that control language functioning and speech. It presents in individuals with progressive and debilitating brain diseases such as Alzheimer's or frontotemporal lobar degeneration. The most common cause of aphasia is head trauma. Therefore, its symptoms typically emerge after an event such as a car accident or workplace injury. However, aphasia can also present itself in patients who have experienced a cerebrovascular accident (CVA), colloquially called a stroke (Corina, *Processing* 317).

Broca's aphasia is the most common type of aphasia. It tends to occur after injuries to the pars opercularis and pars triangularis, regions of the left frontal lobe of the brain. As this area overlaps with the premotor cortex, the distinction between aphasia and apraxia in Deaf signers becomes even less clear. Broca's is also known as 'non-fluent' aphasia due to the staccato, stuttering nature of the speech of people with this type of aphasia. Broca's-aphasic signers demonstrate the same effortful signing that Broca's-aphasic speakers do with speech.

Corina describes several case studies of patients with Broca-like signing. One of them, conducted by Poizner in 1987, was one of the pioneering studies for Deaf aphasia research. Poizner's subject, called G.D., presented with "Broca-like signing", "agrammatic signing and [agrammatic] written language output", and "problems with fingerspelling" (324). Corina also mentions a study done by Douglass and Richardson in 1959 (the case studies prior to Poizner were few and far between). Their subject is described as dysgraphic. Corina says, "Perseverative errors and substitutions were found in all modes of communication", which reflects findings of hearing patients with Broca's aphasia (324).

One suggestion Corina makes is that testing for the presence of agraphia, the inability to write, may help determine if the root cause is apraxia or aphasia. However, this may still end up being unhelpful because sign languages have no written form – the closest is called "gloss", which is when signs are transcribed in the written form of the spoken language (e.g., ASL would be glossed in English). Deaf individuals might have trouble passing such a test even with the absence of apraxia, due to a lack of fluency in their second language.

Wernicke's area, the other most commonly seen type of aphasia, has also been observed in Deaf individuals. Corina includes a 1943 case study of an aphasic Deaf man who presented with Wernicke-like symptoms. He "produced a great deal of signing, much of it wrong or nonsensical, with frequent perseverations, and meaningless signs" (325, 1998). Subject L.K, as described in "Neurobiology of Sign Languages", a chapter of *Neurobiology of Language*, presented with Wernicke-like symptoms following a left anterior parietal lesion in the region of the supramarginal gyrus, or Wernicke's area (Corina and Blau 432). This subject presented with anomic aphasia and had extreme difficulty following even two- or three-step commands. Corina and Blau describe her sign impairment as "profound and long-lasting" (432).

A subject known as P.D., reported in Poizner's 1987 study, exhibited a phenomenon known as paragrammatism. The production of P.D.'s signs was itself fluent – however, "his expression of sentence-level grammatical roles was disturbed" (Poizner qtd. in Corina and Blau 432). Syntactic communication in American Sign Language involves an imaginary plane in front of the signer, within which the signer can attribute a virtual location to people, places, and things. After the initial setup, the signer can use indexing (pointing) to refer to that which already has an established location. P.D. was persistently inconsistent with indexing, forgetting where he had placed people and things. It is not far-fetched to correlate P.D.'s symptomology with Wernicke's aphasia. Interestingly, P.D.'s brain injury was not located in the classical Wernicke's area, but rather "a left subcortical lesion deep to Broca's area, extending posteriorly beneath the parietal lobe" (Corina 432).

In addition to being caused by strokes and traumatic brain injuries, aphasia can also be caused by debilitating neurological disorders such as Alzheimer's. This is known as primary progressive aphasia (PPA). A case study of a Deaf woman with Alzheimer's was conducted by Adam Falchook and his constituents at the University of Florida in Gainesville. In this case, the participant was a 55-year-old Deaf woman whose disorder caused a deterioration of her ability to communicate in American Sign Language (434). Falchook describes her signed sentences as "short and simple, lacking any complex syntax … she only used one question word: WHAT, and she did not use WHO, HOW, WHEN, or IF" (436). He also describes how the woman had great difficulty producing appropriate facial expressions.

Falchook's observations on facial expressions are particularly intriguing. In sign language, facial expressions are absolutely vital to the effective production of the message by the signer as well as the correct understanding of the message by the recipient. David Corina, in an article for *Language and Speech*, discusses two studies in which Deaf signers' facial expressions are analyzed and their implications for the utterance explored. Both studies allow for the delineation of two types of facial expressions present in signed communication. The first of these is known as affective expression. This refers to facial expressions used to convey emotion, which is a ubiquitous discoursal tool. The second of these is linguistic expression, which refers to specific actions taken by signers in order to correctly represent specific ASL grammatical features. Corina's research points toward the idea that hemispheric specialization for facial signals in Deaf signers is contingent upon the purpose of the facial expression. He notes, “Taken together, the data provide important new insights into the determinants of the specialization of the cerebral hemispheres in humans” (Corina 307).

The classification of aphasia in Deaf individuals may be different due to the differing natures of signed and spoken linguistic systems. For example, there are very few spoken languages that involve a system wherein people and things are set up in a physical space. Spoken languages rarely, if ever, use facial expressions to mark certain grammatical features. This calls for a sign language-specific assessment of aphasic symptoms to be developed in order to assure proper diagnostics for Deaf sufferers of aphasia. The impact of aphasia on these sign-specific linguistic aspects has been documented, but what are the implications, and how can Deaf individuals be helped with aphasia?

Audism in the Medical Profession

Speech-language therapy, abbreviated as SLT, is typically the solution for neurolinguistic dysfunction. There are many avenues by which SLT can be administered, but the goal is ultimately to restore the linguistic capacity of the sufferer to pre-injury level. If this proves impossible, then the goal becomes to restore the ability to communicate in any sense. One might imagine that because there is a speech-language therapy, there must also be a signed language therapy equivalent for Deaf people. Unfortunately, none exists.

When one looks for any kind of treatment for Deaf aphasia sufferers, there is startlingly little. The Salk Institute of Cognitive Neuroscience, one of the only institutions in the world to do continuing research in the area of Deaf aphasia, states on their website, “Speech therapy does not help Deaf signers who have had a stroke. No other therapy is available to improve their language” (Salk, 2019). The very first case of a Deaf person experiencing aphasia was documented by Grasse in 1896 (Corina 1998, 318). Over a century later, there is still nothing for Deaf sufferers of aphasia – no therapy, few resources, not even so much as a best practices paper.

If a new speech disorder was discovered amongst the hearing population, it is hard to imagine that no one would try to help and let one hundred years pass with only a select few even noticing. Yet this is exactly what has happened in the case of Deaf aphasia. Jane Marshall, in a 2003 survey conducted at City University, notes that “sign language is vulnerable to neurological damage” (85). She and her constituents sent a questionnaire to all managers of SLT services in the UK, which number 264. A total of 159 questionnaires were returned, signaling a 60% response rate (88). The goal of the study was to determine if Deaf adults have the same access to speech-language therapy as hearing adults.

Marshall and her colleagues found that most referrals were for dysphagia, not aphasia. Dysphagia refers to difficulty of the act of swallowing. Marshall notes that “most teams did not have signing staff members and access to interpreters was variable” (85). Only 29 services, or 18% of respondents, had a therapist who could effectively communicate in British Sign Language. Even fewer (11 services or 7%) had a communication facilitator, assistant, or volunteer. 77% of respondents, or 123 services, had access to BSL interpreters. The study did not mention the credentials, certification, or qualification criteria for the interpreters. Twenty-six services had no access to BSL interpreters and ten did not know if BSL interpreters were available (90).

According to Marshall, there are several reasons for the low referral rate of Deaf patients. One such possibility is that the neurological damage experienced by Deaf people does not typically impair their communication to a noticeable level. However, this is a weak argument because sign language, being a robust and autonomous language, is just as impacted by neurological damage as spoken language would be. She references Hickok's 1998 study, which indicates that both signed and spoken languages "are underpinned by similar neural structures" (91). The other possible reason why Deaf patients are not referred to SLT services is that the healthcare professionals are not knowledgeable enough of sign language mechanics to notice changes in levels of intelligibility of sign communication. She says, "it may be assumed that a Deaf person had limited language premorbidly [before the onset of the neurological damage], simply on the evidence of their speech. That most referrals were for dysphagia supports this view" (91). While family members or friends may notice the changes in the patient's signing style, they may be unaware of the nature of aphasia or think that the problem will go away on its own.

Why is there such a dearth of resources for the Deaf community? The medical profession in the United States has been shown to exhibit prejudice against two people groups in particular: disabled people, and those who do not speak English. The intersection of those two groups is exactly where the Deaf community lies. It is important to note here that lobbing an accusation, at the medical community or at anyone else, is not the goal of the present work. Prejudice can be either explicit or implicit. While some may actively and consciously look down upon Deaf or non-English-speaking people, others may go their whole lives without realizing that signed languages are real languages. Being prejudiced can sometimes be synchronous with being ignorant – and no one can be blamed for what they do not know. However, it is worth pointing out that as knowledge becomes more and more accessible, there are fewer excuses to not know.

In 2016, Jody Cripps published an article in *Communication Disorders Quarterly* entitled “Meeting the Needs of Signers in the Field of Speech and Language Pathology”. Cripps states, “The social stigma for signing and signed language was most overt in the education of deaf children up to the time of civil rights movement in the 1970s” (*Meeting the Needs* 112). After the civil rights movement, it became politically incorrect to ban American Sign Language with policy, but Deaf people continued to be punished at home and in their classrooms for daring to use sign language (*Meeting the Needs 113*). In 1997, Carol Humphries, a prolific Deaf author, professor, and activist, coined the term “audism” to refer specifically to prejudices leveled against Deaf individuals, defining it as “the notion that one is superior based on one’s ability to hear or to behave in the manner of one who hears” (qtd. in Cripps 113). According to Cripps, “Audism is prevalent throughout society, demonstrated by comments, behaviors, attitudes, and beliefs that occur on a daily basis and infer the superiority of spoken language and hearing abilities” (113). To put it simply, the world is not built for Deaf people – and they are painfully aware.

How does such a wide-scale problem even begin to be resolved? The best action one can take is to educate those around them. Hearing and Deaf people alike are raised in a hearing-biased world. While the implicit bias that exists in hearing people may not be able to be fully removed, as it is so ingrained into one’s thought process, it can be deconstructed with conscious effort. Sign language has contributed knowledge to the world in demonstrable ways, yet when it is impacted by disorder in the same way that spoken language is, the medical profession has nothing to offer.

However, the tides may be turning. Alongside his article, Jody Cripps conducted a survey of speech-language therapy students, asking them about their exposure to sign language and their knowledge of sign language disorders. Many of them indicated that they wished their programs included more information about sign language. Additionally, there was a strong interest in learning about signed language disorders. Hope lies ahead that Deaf people may soon be able to receive treatment for aphasia.

Conclusion

Now, the picture is complete. The portrait of the brain has been painted. Sign language has shown itself to be similar enough to patterns of activation in spoken language to be classified as a language in the brain, yet different enough to generate exciting hypotheses in the field of language research. The healthy signing brain has been examined: a brain in which language centers are almost completely analogous to spoken language, and the differentiations between the two are attributed to modality. Lastly, through examining the unhealthy signing brain, it can be inferred that sign language is equally disrupted by dysfunction. If one only looked at neuroimaging scans, it would seem obvious to conclude that sign language is in fact a sovereign and autonomous language, affected by neurological disorder. There is societal, linguistic, and now neurological proof that sign languages are valid. Yet, throughout the world, sign languages are still not treated with equity.

Because Deaf people have the same neurological structures in the brain associated with language, many Deaf people who experience neurological trauma in those areas will have trouble with signing. Hearing people have an entire field of study devoted to helping those who speak with their mouths: speech language pathology. Yet there is no equivalent for the Deaf community. Deaf people whose language centers have been impacted by neurological trauma, communication disorders, and developmental disabilities are left without language and without crucial resources needed to enact early intervention. Even the Salk Institute for Cognitive Neuroscience, one of the only institutions that is performing extensive and comprehensive research on Deaf aphasia, has stated outright that there is no treatment available for these people. Despite over one hundred years of documented cases of Deaf aphasia, not one model of therapy has been developed. Signed language pathology is nonexistent. There is a sect of the population that cannot speak – and they cannot do anything about it. If there was a new spoken language disorder identified, and nobody searched for any kind of answer or solution, there would certainly be backlash, but when it happens to be Deaf people, there is virtually no response.

How can this problem be solved? The answer is awareness, but the solution takes a collective effort to enact. Although the Deaf are a minority, they deserve the same respect as everyone else. By looking into the hard science behind how the brain works, it can be seen that sign languages are entirely sovereign languages. Not only that, they have cultures attached to them, exactly like spoken languages do. However, language does not exist in a vacuum – it is affected by so many other factors. One of these factors that impacts the Deaf brain is its physical structure, which can be warped by trauma and by communication disorders. This results in linguistic impairments such as aphasia. Unfortunately, there are currently no resources for Deaf individuals with aphasia. More and more people are starting to realize the sovereignty and autonomy of ASL as a language – yet so much of the world remains inaccessible to the Deaf, including therapy for communication disorders.

The ultimate solution is to deconstruct attitudes of not only ableism, but linguistic superiority in the medical profession, for it is in the Deaf community that these two prejudices intersect. It has been shown time and time again that medical professionals are biased towards speakers of English, as well as able-bodied people, either implicitly or explicitly. In this case, Deaf individuals are a double minority – not only does their Deafness represent a disability, but their usage of sign language instead of spoken language represents a step away from the norm.

The development of sign languages is in fact one of the most amazing and eye-opening stories of human adaptation. What was once merely an audiological condition denoting lack of hearing, over decades of rich tradition and history, has become something so special and unique that the hearing realm of linguistic research is finally turning its eye to notice it. Deaf people have created languages for themselves. They have created fellowship where there was loneliness, family when they were excluded from their own, and communication where before, there was isolation. They have created artwork, poetry, and literature. The study of their language has been invaluable to researchers everywhere, generating new hypotheses and implications for spoken language with each new study released. It is time to give back to them as they have given.

Now that there is a developing body of knowledge as to the neurological foundation of sign language, the information will likely slowly disseminate from the realm of academia out into the rest of the world. However, people who are already aware can accelerate the process by sharing with their friends and family what they now know about the signing brain. Science and society are often thought of as separate, but they are in fact entwined. The priorities of any given society will inform the research that is produced by that society. If accessibility is prioritized, then ultimately, research will start to reflect that.

Accessibility needs to be emphasized so it can become normalized. Most importantly, the academic community needs to talk to Deaf people: about their lives, their experiences, and their struggle for accessibility. It is imperative that they are listened to with humility and not defensiveness from hearing people. Society has learned a lot from the Deaf, perhaps more than the average person may know about, but there is so much yet still to learn through interacting with each other with curiosity and a genuine desire to improve the lives of people, both now and going forward into the future.

The history of the Deaf is rich. The culture of the Deaf is vibrant. The language of the Deaf is beautiful. For too long, these things have been overlooked. After the Civil Rights Movement of the 1960s, linguistic and cultural minorities learned that they could fight for themselves as a collective, and the practice of not only self-advocacy but others-advocacy became apparent among these groups. Indeed, this has been happening in the Deaf community since 1988, when Deaf individuals rallied together as a community to advocate representation at Gallaudet University through the Deaf President Now! protests. At this juncture, Deaf public figures like Nyle DiMarco and Marlee Matlin advocate for Deaf rights on a national level. Through the tireless work of Deaf advocates, the world is slowly but surely starting to come to terms with the fact that sign language is here to stay. With the choice to recognize sign language as a language, society must also choose to adopt its responsibilities as well as its rewards. This includes providing consistent, culturally appropriate, and accessible help for those affected by communication disorders. Every person has a voice, and every person's voice deserves to be not only heard but seen as well.

Works Cited

Campbell, Ruth. "Sign Language and the Brain: A Review." *Journal of Deaf Studies and Deaf Education,* vol. 13, no. 1, 1 Jan. 2008, pp. 3–20. This is a literature review written by Ruth Campbell, Mairéad MacSweeney, and Dafydd Waters, all three of whom are researchers with University College London. The review starts with a "tour of the brain" (3), describing basic brain anatomy and how the brain receives information. Next, the authors give an overview of the history of studying the brain. The authors report that people have been studying the brain "since antiquity" (3), but only in the mid 19th century did the brain's use of language become an established field of study: neurolinguistics. The authors go on to describe the practice of inferring brain function from lesion studies (something that the present paper will discuss). Campbell's comprehensive yet succinct overview will contribute much of the basic information that the paper will need to convey in order to maintain the ideal of accessibility for people of any education level.

Capek, Cheryl M., and Helen J. Neville. "Studying Sign Language Processing Using Functional Neuroimaging Techniques." *Research Methods in Sign Language Studies,* 2015, pp. 319–335., doi:10.1002/9781118346013.ch17. This is a chapter from the book *Research Methods in Sign Language Studies,* a practical manual for anyone wishing to do research involving Deaf individuals or signers in general. It will be used in the first section of the paper, where modern imaging studies are described. The chapter discusses functional magnetic resonance imaging (fMRI) first. This is followed by electroencephalography (EEG or ERP). Next, Capek introduces magnetoencephalography (MEG). Finally, transcranial magnetic stimulation (TMS) is talked about. Discussing the different pros and cons of various neuroimaging techniques is helpful for analysis of neuroimaging studies and pointing out what can be improved upon.

Corina, D. P. "The Processing of Sign Language: Evidence from Aphasia." *Handbook of Neurolinguistics*, 313-329, edited by Bridgette Stemmer, Acad. Press, 2002, pp. 313–349. This book describes many of the topics and trends in neurolinguistics at the time of the writing (1998). The chapter that will be featured in the present paper is by David Corina, a leading researcher in sign language aphasia, and is meant to document the current status of sign language aphasia studies and "foreshadow issues that are likely to be of interest in future studies" (313). It is good to have materials from both the past and the present so that aspiring researchers can learn from the history of the practice.

Corina, D. P., Bellugi, U., & Reilly, J. (1999). Neuropsychological studies of linguistic and affective facial expressions in deaf signers. *Language and Speech*, 42, 307-31. Retrieved from http://ezproxy.gardner-webb.edu/login?url=https://search.proquest.com/docview/213724082?accountid=11041 This is a study performed by David Corina, one of the leading researchers in the field of sign language aphasia. In this study. Corina et al. makes an effort to differentiate between affective (emotional) and linguistic facial expressions. Corina notes that this is quite an interesting finding because although it is the same muscular system that is being applied, Deaf people use the same system for two distinct purposes. Additionally, this provides a unique perspective on a grammatical feature that is not present in spoken languages. In spoken languages, facial expressions are paralinguistic, meaning that they are an added element of communication. In sign languages, facial expressions contribute to the grammaticality of an utterance. This is an important aspect of sign language neurolinguistics, as it activates brain systems used for producing (as well as recognizing) facial movements.

Corina, David P., and Shane Blau. "Neurobiology of Sign Languages." *Neurobiology of Language*, 2016, pp. 431–443., doi:10.1016/b978-0-12-407794-2.00036-5. This book is a collection of entries concerning neurolinguistic topics that have been studied in the past fifteen years. Among them is the neurobiology of sign. Sign language aphasia is the first topic discussed, with the author describing Broca-like signing and Wernicke-like signing as it presents in Deaf individuals. Next, the author describes right hemisphere damage and their effects on the Deaf language experience. It has been observed that Deaf people who experience right hemisphere damage often notice disruptions in their discourse patterns. For example, the individual may be inconsistent in their use of spatial referents, an important aspect of ASL grammaticality. Because spatial reference, or "talking with your hands", is not a key aspect of spoken language grammaticality, this finding may further differentiate spoken and signed languages.

Corina, David P., et al. "Language Lateralization in a Bimanual Language." *Journal of Cognitive Neuroscience,* vol. 15, no. 5, 2003, pp. 718–730., doi:10.1162/089892903322307438. Another excellent source from Corina and colleagues, this is a study in which participants' brains were examined during articulatory sign language demands using a neuroimaging technique called positron emission tomography. Participants, of which there were sixteen, generated verb signs independently with their right dominant and left nondominant hands. These participants were all deaf users of American Sign Language. This study references many pertinent topics to neurolinguistics, perhaps most importantly the visual word form area (VWFA), a debated area of the brain. This region of the brain, hypothesized to "reflect modality-specific processing of prelexical orthographic featural properties" (725), showed activation during sign language production tasks. This points to the brain's reception of signs as being more similar to word recognition and not just gestural recognition.

Cripps, Jody H., et al. "Diagnosing and Treating Signed Language Disorders: A New Perspective." *Contemporary Issues in Communication Science and Disorders*, vol. 43, 2016, pp. 223–237. This study is a survey of speech-language pathology students at the graduate level. Its goal was to determine their awareness surrounding Deaf culture and sign language, their perspective on American Sign Language (ASL) as a true human language, and their knowledge of resources for Deaf individuals who experience language disruption. Thirty-two students completed the survey, which is somewhat problematic since the opinions of thirty-two students cannot be extrapolated to the state or the country, but it is an important start and it shows the attitudes of those certain graduate students towards ASL, which were generally favorable. Almost all participants expressed a desire for ASL-specific training so as to help signing individuals with communication disorders.

Cripps, Jody H., et al. "Meeting the Needs of Signers in the Field of Speech and Language Pathology: Some Considerations for Action." *Communication Disorders Quarterly*, vol. 37, no. 2, 2016, pp. 108-116. Here, Cripps et al. review the options for users of sign language who have experienced neurological trauma. They are, as he notes, tragically few. In fact, even the Salk Institute for Cognitive Neuroscience states that there is no therapy available for Deaf individuals with aphasia. Cripps describes the prevalence of sign language aphasia (about 20% of Deaf individuals who suffer strokes are left with lasting aphasia), as well as the prevalence of sign language stuttering (a subject that has been heretofore largely left undiscussed – no studies suggesting its prevalence were cited). The authors conclude that the prejudice against linguistic minorities in the medical profession is ultimately the problem, and that in order to help sign language users with language disorders, those negative attitudes must be deconstructed and eventually removed from the society in which Deaf individuals live and function.

Falchook A. D., et al. “Sign Language Aphasia from a Neurodegenerative Disease.” *Neurocase,* vol. 19, no. 5, 2013, pp. 434–44., doi:10.1080/13554794.2012.690427. Adam Falchook, of the Cognitive and Memory Disorder Clinic at the University of Florida, published this study in 2013. It is a case study of a 55-year-old congenitally Deaf woman who had been diagnosed with Alzheimer’s disease. The type of aphasia that results from neurogenerative disorders is called primary progressive aphasia, and it is documented here. The study is important as it points to the fact that Deaf people experience language dysfunction just the same as hearing people do when they have a neurological disorder.

Gordon, Neil. “The neurology of sign language.” *Brain and Development*, vol. 26, no. 3, Apr. 2004, pp. 146–150., doi:https://doi.org/10.1016/S0387-7604(03)00128-1. This is a short article detailing some of the research that has been undertaken in an effort to prove the sovereignty of sign languages. It is a succinct synthesis of some recent research as well as some insight by the author. Gordon discusses discoveries that have been made both by lesion studies and by modern neuroimaging studies. He also references many case studies, spanning all different types of aphasia.

Gutierrez-Sigut, Eva, et al. “Examining the Contribution of Motor Movement and Language Dominance to Increased Left Lateralization during Sign Generation in Native Signers.” *Brain and Language*, vol. 159, Aug. 2016, pp. 109–117., doi:10.1016/j.bandl.2016.06.004. This study, headed by Eva Gutierrez-Sigut, Heather Payne, and Mairéad MacSweeney, examines neural systems supporting speech and sign processing. Specifically, they wanted to determine if the left or right hemisphere was more strongly lateralized during sign language production (the study was performed in Britain; signers used British Sign Language [BSL]). During the study, Deaf native signers performed semantic and phonological fluency tasks in both covert and overt methods. Their brains were examined using fMRI techniques. The study found greater patterns of left-hemispheric activation for all participants in all four task groups. This will contribute to some of the current paper's discussion on lateralization in Deaf individuals.

Knapp, Heather Patterson, and David P. Corina. "A Human Mirror Neuron System for Language: Perspectives from Signed Languages of the Deaf." *Brain and Language*, vol. 112, no. 1, 2010, pp. 36–43., doi:10.1016/j.bandl.2009.04.002. This article covers a controversial theory of neurolinguistics: the mirror-neuron system. In the brains of macaque monkeys, a structure has been discovered that activates when viewing action as well as participating in action. Knapp and Corina predict that if in fact the mirror-neuron system is completely homologous between humans and macaque monkeys, there should be no selective impairment between linguistic and nonlinguistic action processing in signers. They conclude that there is only partial evidence to support the idea that the nature of the mirror-neuron system mediates both language production and comprehension. The mirror-neuron theory, while still being hotly debated, is necessary to include in a discussion of neurobiology as it does have important implications for signers.

Mahadevan, Vishy. "Neuroanatomy: an Overview." *Surgery (Oxford)*, vol. 36, no. 11, 2018, pp. 597–605., doi:10.1016/j.mpsur.2018.09.010. This article by Vishy Mahadevan goes over essential neuroanatomical information. Mahadevan starts from the cellular level, and then proceeds to describe the central and peripheral nervous systems, both anatomically and physiologically.

This article contains essential basic information and terminology that provides the context for more complicated neuroscientific discussion.

MacSweeney, Mairéad, et al. “Dissociating Linguistic and Nonlinguistic Gestural Communication in the Brain.” *NeuroImage*, vol. 22, no. 4, 2004, pp. 1605-1618/. ProQuest/, http://ezproxy.gardner-webb.edu/login?url=https://search.proquest.com/docview/1506613920?accountid=11041, doi :http://dx.doi.org/10.1016/j.neuroimage.2004.03.015. The goal of this study was to examine patterns of brain activation when trying to comprehend a visuospatial language (in this case British Sign Language), as well as trying to comprehend a non-linguistic visual communication system (in this case TicTac, a manual-brachial code used to convey odds in horse racing). The brain activation patterns were realized through the use of fMRI technology. All signers had greater brain activation in their left hemisphere than the right. Nonsigners tended to experience more activation in the right hemisphere. The findings of this study emphasize that the neurological processing of gestures and signs are differently organized within the brain’s structure.

Marshall, Jane, et al. "Aphasia in a User of British Sign Language: Dissociation between Sign and Gesture." *Cognitive Neuropsychology*, vol. 21, no. 5, July 2004, pp. 537-554. EBSCOhost, doi:10.1080/02643290342000249. This case study, led by Jane Marshall et al., describes a Deaf man (referred to as “Charles” in the text) with speech anomia, the most common type of aphasia in which the person cannot think of the name for something – these people always have words “on the tip of their tongue”. The study found that there were distinctive differences between sign and gesture. The iconicity or arbitrariness of signs did not matter; the gesture production was superior to sign production, even if the forms were similar (537).

Marshall, J, et al. "Is Speech and Language Therapy Meeting the Needs of Language Minorities? The Case of Deaf People with Neurological Impairments." *International Journal of Language & Communication Disorders*, vol. 38, no. 1, Jan-Mar2003, pp. 85-94. EBSCOhost, ezproxy.gardner-webb.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=rzh&AN=106830845&site=ehost-live. The UK is a very culturally diverse arena containing many linguistic minorities. One of these minorities is the Deaf population, who use British Sign Language (BSL) to communicate. The article attempts to discern if this sect of the population is being effectively helped by speech and language therapy (SLT) services. The results suggest that many Deaf do not have access to SLT after an incident of neurological impairment. The options for Deaf individuals are remarkably slim.

Okada, Kayoko, et al. “An FMRI Study of Perception and Action in Deaf Signers.” *Neuropsychologia*, vol. 82, 13 Jan. 2016, pp. 179–188., doi:10.1016/j.neuropsychologia.2016.01.015. This is another study that offers insight into the mirror-neuron theory for human language. Okada and colleagues recruited sixteen participants, all of whom were lifelong signers born to Deaf parents, and examined their brains through functional magnetic resonance imaging while they watched videos of people performing actions and then imitated those same actions themselves. These included things like swinging a tennis racket or playing a guitar. Subjects also performed a naming task that required them to name the action that they were viewing. The study confirmed the co-activation of Broca’s area in the execution and observation of sign language (186). However, the nature of the co-activation is yet to be determined.

Petrides, Michael. Neuroanatomy of Language Regions of the Human Brain. Academic Press, 2014. This book, published in 2014 by Academic Press, will contribute neuroanatomical information insofar as it relates to the production, processing, and comprehension of language. It ties together two important topics: anatomy and physiology of the brain, and language.

"Sign Language Research." Laboratory for Cognitive Neuroscience at Salk Institute for Biological Studies, lcn.salk.edu/asl/index.html. This short blurb from the Salk Institute for Cognitive Neuroscience, the leading institution performing research on Deaf aphasia, simply states that there is no treatment available for Deaf people with aphasia.

Squire, Larry R., editor. Encyclopedia of Neuroscience. Elsevier, 1999. The Encyclopedia of Neuroscience is intended to be an exhaustive resource on all things neuroscience. There are over one hundred entries in the encyclopedia. This paper will refer to several of them when discussing neuroanatomy, especially specific structures like Broca's and Wernicke's areas. This resource will also contribute to the section on cytoarchitectonics, which is the study of the physiological structures of various parts of the brain and how the differentiation in materials impacts what the parts are used for. Areas of the brain divided by cytoarchitectonic structure are called Brodmann's areas.

Zilles, K., et al. "Cytoarchitecture and Maps of the Human Cerebral Cortex." Brain Mapping, vol. 2, 2015, pp. 115–135., doi:10.1016/b978-0-12-397025-1.00207-4. This article provides information about the cytoarchitectonic structure of the brain. It is important to have basic information about these brain structures before their relation to language can be demonstrated. The article also contains pictures and maps of the human cerebral cortex, further contributing to the understanding of cytoarchitectonics.