Fundamentals of language Acquisition

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Week 11

Lecture 051

Lec 51: Language areas in the Brain

Hello, we will start with Module 11 today. Module 11 deals with brain and language development. So, in this module, we will try to track some of the developments in language acquisition through various stages. We have already seen throughout this course that language development happens step by step: in the beginning, sound segmentation, understanding and recognizing sounds, producing sounds, followed by the one-word stage, and so on. In this module, what we will try to do is see if there is a parallel between the language development stages and the brain development stages, or what areas in which certain kinds of language acquisition activities have been tracked, and so on. Of course, this is just one module, so we would not be able to give you the entire body of literature, but this is meant to give you a brief overview of the main points of discussion, the main theories, and so on.

So, we will start with a bit of understanding about the anatomical, structural, and functional structure of the brain, and slowly we will build up the other parts. So, first we will look at the language areas in the human brain, followed by brain mapping methods and milestones in language development. When we talk about brain mapping methods, we will be discussing some of the methods, not all, mostly those that are more commonly used for child language acquisition research. So, then lecture 3 will be on brain development and the neural correlates of language acquisition, and in lectures 4 and 5 we will look at bilingualism and its impact.

So, in the beginning, we will talk about first language acquisition and its correlation with the structural aspects of the human brain, and in the last part, we will look at second language acquisition. So that we cover the major tenets of research in both domains, both first and second language acquisition. So, to start with lecture 1 today, here we will look at the anatomical and functional organization of the brain in terms of some of the historical findings as well as some of the latest ideas, the hypotheses that have been put forward. So, first things first, the basic structure of the human brain. To start with, of course, all of you know that the human brain has two hemispheres, the left and the right hemisphere.

So, this is a paired sort of organ just like we have other paired organs, such as the lungs, but there are some crucial differences. So, one of the most crucial aspects of the human brain is that the functions are unique to each. Some functions, of course, overlap, but on a broader scale, each of the hemispheres has a unique set of functions with respect to human life. And when these two functions are two different kinds of functions located in two hemispheres, they primarily exhibit asymmetry, as there is no one-to-one mapping between the left and right hemispheres. And unlike other paired organs, there is typically what happens: both of your lungs will be functioning the same way, just like the kidneys do.

However, the brain does not do that. So, that is why we call them asymmetrical functions, meaning the two hemispheres do two different things. This, alongside the fact that there are some functions and processes that have a counterpart in the left hemisphere or are being done in the right, means there is some counterpart on the left and so on. But overall, the broader picture is that they are asymmetrical. And then another interesting aspect of the human brain is that its control mechanism is contralateral. Contralateral, as in the right hemisphere controls the left side of the body and the left hemisphere controls the right side of the body. So, it has a contralateral design, which is typical of all vertebrates. But in the case of invertebrates like worms and others, this is a simple one-to-one mapping. So, right brain, right body, left brain, and right body kind of an organization. So, these are the first few important and unique aspects of the human brain.

Now, look at the organization of the human brain. Now this human brain has intrigued scientists and philosophers alike for a very, very long time. As a result, there are a number of different ways of looking at the brain. So while we look at the structure, when we are also looking at the anatomical aspect of the brain, there are different kinds of approaches. So, the most simplistic way of looking at it is the gyral-sulcal organization.

That is something you see with your naked eye. What does it mean, basically? The brain is a convoluted structure; it is not a simple spherical object. It has a convoluted surface, which means that there are some raised parts, some grooves, and so on. So, that is how the human brain is structured. Basically, if you can mentally open it up, you can kind of straighten it out. So, it is not a straight structure. It is a convoluted structure. So, there are raised parts and there are some deep grooves. So, this is what is called the gyral sulcal structure of the human brain. So, for example, the folds will be something like this: much more tightly organized. So, the top raised parts are called gyri, the deep faces are called sulci, and you can refer to them as sulci. So, this is the reason why it is like this: the idea that has been put forward kind of minimizes a lot of surface area into a very, very small place, a very, very small three-dimensional volume, which, actually, if you open it up, as I was just saying, will be a large area. So, much of that part of two-thirds of the cortex lies within the sulcus. So, two-thirds, you know, is a major part of the structure that is actually in the deeper groove structure. Also, because of this kind of structure, it reduces the amount of axonal wiring that is needed for transmitting various kinds of signals across the areas in the brain.

So, that is also a very good outcome of this kind of structure. Another important thing is that although the same major areas are visible in all human beings, they are present in all human brains. However, there are certain differences that are often genetically influenced. So, broadly the structure remains the same, but at a more minute and more subtle level there are differences across humans. So, intersubject differences are visible, which are very often genetically influenced in terms of what kind of structure one will end up with.

That is one that is broadly applicable; if you look at the brain structure broadly, you get the sulci and the gyri. So, the organization of sulci and gyri is the first thing that you notice. Next comes what we call the cytoarchitectonic organization. This is basically looking at primarily the cortical area, which has layers. So, if you are looking at the way the morphology, the function, and the interconnectedness of certain parts of the cortical region, that is what we were looking at when we were talking about cytoarchitectonic organization.

So, the cortex is made up of 6 layers, with different layers stacked one on top of another. So, there is a multi-layered structure; you can look at this picture that makes the idea clear. So, there are 6 layers, and each layer has not only a different kind of organization and a different kind of morphology, but it also has different connectional properties. Each layer is characterized not only by the morphology of the cells within it but also by the connectional properties. Layer 1, 2, and 3 communicate with other cortical areas.

Layer 4 receives input from the thalamus. Layer 5 sends output to subcortical areas, and Layer 6 sends output to the thalamus. So, the thalamus is below the cortical region. So, the connection between the thalamus and the cortical region, from one cortical area to another cortical area and then from cortical to subcortical. So, there are various kinds of communication and various kinds of connectional properties that these layers have attributed to them. So, perpendicular to these horizontal layers are vertical columns measuring 0.5 mm and consisting of roughly 100 neurons. So, these columns are considered the basic functional units of the cortex. So, this is what the cytoarchitectonic structure gives us. Now we will talk about the brain, the structure of the brain, the areas of the brain, and the division of the brain into different domains.

Of course, there are many important names, but one of the names that we are still using, his research output, and the ideas that he gave is the name of Korbinian Brodmann. He was a German neurologist who published the most famous map of the human brain in 1909. This map, from those days in 1909, shows that they did not have the kind of machines that we have today. So, it was a drawing of the lateral and medial views of the brain with respect, drawn from his understanding, his inferences, and his studies. He was famous for dissecting brain in his kitchen. So, at the end of all the studies, he came up with a map of the human brain. So, he segregated the entire cortical region into 43 cortical areas and named them as area 1, area 2, area 3, area 4, and so on, until area 43. So, initially he had more areas, and eventually he fine-tuned them and reduced the numbers. So, some of the regions that were found in other mammalian species were not found in humans. So, he later deleted them from his number of areas and so on.

So, he had some of the areas that are still used today. Many of the areas he mentioned are called Brodmann's areas, such as Brodmann's area 1, Brodmann's area 2, and Brodmann's area 3. Many of them are still used today. Even though things have changed over time, we now have a lot more finely tuned machinery to examine brain areas. In fact, today we can even go for single-cell recording. So, things have changed drastically. So, as a result, they have been updated; the areas have been updated, but many of the areas still exist; I mean, we still use them. So, this is the map that we have. So, I have not marked all of the areas here; I have just taken this picture, which shows us the main language areas and language-related areas. So, you can see area 4 here; this is the primary motor cortex, and areas 44 and 45 are our Broca's area, which is one of the most important areas in the brain when you talk about language.

And then we have areas 1, 2, and 3, which are the primary somatosensory cortex. Now, this is the whole brain, and this is the medial surface. So, it is kind of a structure. This is the entire brain. So, these are two views of the same thing. So, this is where your primary somatosensory cortex is, and then we have the primary motor cortex here, which you can see, and then areas 39 and 40 are Wernicke's area here, and these are the most important areas. Of course, we have the primary visual cortex at the back of the brain in the occipital lobe and so on. So, these are the main areas where we are still using these numbers. So, some of these areas that we might be talking about often are areas 1, 2, and 3, which include the primary somatosensory cortex, postcentral gyrus, area 4 (primary motor cortex), area 5 (somatosensory association cortex), and so on. So, many of these areas end with areas 44 and 45, which are Broca's area and 22,39 and 40 Warnicke's area.

So, these are the areas that are more relevant for our purposes. So, with respect to Broca's area, many of you might already be familiar; Broca's area is located at the base of the motor cortex. It is responsible for organizing the articulatory patterns of language and directing the motor cortex when we want to speak. So, basically, controlling the mechanism of articulation in language is what Broca's area does. So, it controls the use of inflections, tense, and number, as well as function morphemes like determiners and prepositions, and so on. Recent research has also found evidence of the involvement of this area in the comprehension of tasks. So, this was a TMS (transcranial magnetic stimulation) study where it was found that Broca's area can also contribute to comprehension. So, of course, more and more recent findings are coming out. So, we are updating the idea, but the earlier idea was that Broca's area is primarily responsible for articulation. Wernicke's area, on the other hand, is located near the back section of the auditory cortex.

This part is involved in comprehension, primarily in understanding. So, this is the comprehension of words and the selection of words when producing sentences. That is why, when we have Wernicke's aphasia, it is an acquired disorder. So, Wernicke's aphasia happens when there is a problem with the Wernicke's area; it is not functioning as it should, either due to a stroke, some head injury, or whatever. In that case, what happens is that if Warnicke's area is affected, language production will not be problematic; it will not be affected, but what will be affected is the comprehension.

So, that is why it is called fluent aphasia. So, the patient might go on talking not in words or sentences, but in paragraphs; however, there will be no sense to it. So, that is what Wernicke's aphasia is about because that area is responsible for comprehension. On the other hand, if Broca's area is affected by an injury, tumor, or something else, it will result in Broca's aphasia, where comprehension is intact but production is difficult, making articulation very, very challenging. The other cortical areas related to language function are the auditory cortex, the visual cortex, and the motor cortex.

It is self-evident why they are important. The auditory cortex is important because spoken language is based on the vocal auditory loop, as we call it. So, as I speak right now, I can hear myself speaking. So, if there is a mistake that I make, I will be able to correct it. That is about your own speech. And then, of course, when you hear other people talking, the auditory cortex plays a very important role, because that is where you get the spoken input.

So, that is why the auditory cortex and visual cortex are important: a large amount of our language input comes through the visual domain; we read or see signboards and all that. So, the visual cortex is very important for language and the motor cortex, of course, because it is very important for the production of speech. So, the visual cortex lies at the lower back of each hemisphere, receives and interprets visual stimuli, and is thought to store images. And then the motor cortex is in the upper middle of each hemisphere; we have just seen the picture, and this is responsible for sending signals to the muscles, including the jaw, face, tongue, and so on. So, these are the very basic primary areas we used to call the motor cortex.

In terms of the brain, if we just say motor cortex, we are actually talking about a large room, you know, kind of if we compare it, because within the brain, each small 1 centimeter by 1 centimeter area is also a huge area, because there are those tiny domains which can have different functions. So, earlier we used to talk; we used to say this, auditory cortex, visual cortex, motor cortex and so on. So this is another picture for you to get a better idea. This entire thing is Broca's area. Then we have the primary motor area, the primary sensory area, and then the posterior speech area, and so on.

So these are the basic areas of the brain that we call language areas. This is just for representative purposes. Now, we also have something called a connectional organization. So, not only are there various regions, but we need to have a connection between, you know, one area and another area; they need to talk to each other, they need to connect to each other in order to function. So, for any human to function normally, not only should the visual apparatus work and the auditory apparatus work, but they should also work together.

So, connections are very important. So, the human brain also has some, so to say, highway-like structures, as we will just see. The structural areas of the brain cannot operate in isolation; they depend on a massively interconnected network, giving rise to complex mental functions. So, there are lots of interconnections, as we saw in a very minuscule scale in the case of cytoarchitectonic architecture; how within the cortex, in a very tiny area, there are 6 layers, and each layer has different functions and different kinds of connections. But on a larger scale, there are also many connections between different broader areas. So, the dynamic cooperative interplay of signals carried by bundles of axons coursing through pathways along the white matter is what we are talking about here.

This is akin to the highways that we see connecting cities. The biggest and there are many such connecting tissues; there are many such connecting pathways. The most important, biggest, and most visible one is the corpus callosum, which houses more than 100 million axons interconnecting the hemispheres. In fact, there is research that has been carried out.

When we want to look at the workings of a particular hemisphere, we can understand if we can artificially disconnect the brains by putting the corpus callosum to sleep or by putting one particular hemisphere to sleep, in order to understand the workings of the other part of the brain.

So, anyway, the corpus callosum is the biggest connecting highway, so to speak. Now, in terms of duties, what do the hemispheres do? The right hemisphere, of course, controls the left part of the body. But otherwise, the most important functions are those that any textbook will tell you. But roughly most importantly for our purposes, the right hemisphere looks at spatial acuity, the awareness of position in space in all directions simultaneously. So, it is right for any person to be standing upright and, with respect to the things that are surrounding them, being aware of their surroundings; all of that is taken care of by the right hemisphere.

The left hemisphere handles abstract reasoning, physical tasks that require step-by-step progression, and of course, our own language. So, just to give an example of how even the apparently similar kind of input can be based on the property on which we are trying to understand them, they can be processed in different parts of the body. One good example is prosody. Now, prosody in some languages can be reflected through tone. In some languages that are non-tonal, prosody might reflect the emotional aspect of the speech.

So, for example, if we are angry or we are, you know, at a cross with somebody. So, the language, the pitch will go up, or our tone or the intonation pattern of the speech will change. So, in this case, it is not a tonal language, but with tone and pitch, we are trying to express certain kinds of emotional states, which is one aspect of prosody. The other aspect could be that the tonal language, like Chinese, is a tonal language; many of the languages in Northeast India are tonal languages. So, here tone has a semantic purpose; it is not about emotion, but it is about the semantics of the words, the sentences, or whatever.

Now, the pitch of voice in both cases will carry the information, be it semantic information or the additional paralinguistic kind of information like emotion, attitude, and so on. Now, the brain's processing of each of this information will differ depending on what it is that we are processing. So, this is seen as various kinds of neuroimaging studies have shown this using different state-of-the-art machinery. So, emotional changes in pitch engage the right hemisphere, primarily in the right frontal and temporal regions. So, when we are aware of when the prosody reflects the emotional state, it gets processed in the right hemisphere.

A different pattern of brain activity occurs when pitch is used to convey semantic information. So, for example, in the case of Thai speakers, the left frontal lobe is consistently activated in response to changes in tone. So, we are talking about prosody in both cases: if it is emotion, it is in the right hemisphere; if it is tone, it is in the left hemisphere. So, you see the point of how fine-tuned the entire system is. So, even if the larger domain is prosody, depending on what the exact variable is here, which is pitch in our case, what is that variable doing? If it conveys meaning in the sense of semantics, then it is processed in the left hemisphere.

If it is conveying a paralinguistic meaning in terms of emotion, attitude, or other kinds of non-linguistic information, then it will be processed in the right hemisphere. So, that is what this particular example shows. Now, based on how the brain functions and how the different domains are interconnected, the most famous and classical model is, of course, the Wernicke-Geschwind model. It goes back all the way to the time of Geschwind. This was a connectionist model of language processing stemming from the work of both Broca and Wernicke. And now this model is not just an anatomical model, but it is also a functional model because, based on this model, the idea of the various kinds of aphasias was also proposed. So, this classical model of language processing was the first model proposed to capture how the adult brain processes linguistic stimuli. So, this model relies on a single word processing and deficit-lesion association in stroke patients. So, what does a deficit lesion mean? As a result of a stroke, the most common causes of aphasia will be a stroke or a head injury. So, in the case of a stroke, if there is a particular kind of, you know, deficit in language production or language comprehension, let us say it is a deficit in comprehension.

So, there is no problem with the articulation; the patient can speak a lot, but comprehension is lacking. So, they are not making any sense when they speak, or they do not understand what the other person is saying. So, that is the deficit. Now, a lesion is the problem where, let us say, an injury has happened in the brain. So, that is the connection between the deficit and the lesion, an injury to the brain; based on that mapping, this model was discussing the different kinds of aphasia. So, if the lesion is in Wernicke's area and you have lost your sense of comprehension, then that means that area is processing comprehension and meaning. This is the basis on which the model was proposed. So, this is basically in very simplistic terms what the model is all about. It proposes an interplay between the left inferior frontal region, which is Broca's area assumed to support language production, and a posterior temporal brain area, which is Wernicke's area claimed to subserve language comprehension, and these areas are structurally connected by the arcuate fasciculus fiber bundle.

As I said, there are many connections and many highways. So, this is the highway that this model focused on and talked about. This model serves as a foundation for classifying the types of aphasia. So, as you can see, if there is a problem in Broca's area, then you have Broca's aphasia. Similarly, in Wernicke's area, you will have Wernicke's aphasia. So, this is how the connection was, and this is how language processing was supposed to work.

So, if there is a problem, if there is a break in the processing somewhere, then accordingly, depending on where the break is, you will have different kinds of aphasia. That was the Warnicke-Geschwind model. But in the meantime, there have been many changes; a lot of new data has come in. So, research on language neurobiology has undergone a paradigmatic shift primarily due to the various kinds of brain imaging techniques that have emerged, such as fMRI, EEG, and so on. because of all of that, we now have a lot more data, and it is now known that the canonical Broca's area is composed of at least 10 sub-areas or sub-regions.

As I was just telling you a little while back, when you talk about areas, if we say "visual cortex," it is a huge area in terms of the brain; it is a very big area. So, now we know that even the area that we have been referring to in the textbooks as Broca's area is responsible for performing articulation as well as certain grammatical functions. Now, we know it is not just a simple, homogeneous area; it has 10 subregions within itself. Now, if there are 10 different regions within that area, the chances are very high that there will be at least 10 different functions that this entire area is performing. So, these are some of the later, more recent findings; one of them is, of course, this 2010 publication.

And similarly, language-relevant areas extend beyond the classical regions. So, we started with Broca's area, Wernicke's area, and the three cortical domains: visual, auditory, and motor cortex. But now we know that these are called classical areas, classical regions, classical language areas, and so on. Now, we know that language areas actually extend far beyond this; it is not limited to this. Now, new findings suggest that language areas include regions in the right hemisphere as well. And similarly, along with the right hemisphere, there are many other subcortical structures that are also part of the larger network responsible for language, for example, the cerebellum, the thalamus, and the basal ganglia.

These areas are also important for processing language. This is about the anatomical area. Now, in terms of connectivity, we initially knew only about the arcuate fasciculus connection, but now we know that there are many more connections that are also responsible. So, the connectivity of these regions is much more complex than initially proposed. This is certainly not restricted to the arcuate fasciculus only. There are many other regions; one of the most important names in this domain is, of course, Eve Fedorenko and her group. They have found that there are minute differences even within the classical areas as well as in the classical understanding of the networks. So, the arcuate fasciculus is now known to be a bidirectional tract that interconnects larger areas of the sensory cortex with the prefrontal and premotor areas. So, we now have a lot more understanding and a lot more knowledge about the finer aspects of each of these brain areas. Based on the later findings, based on these later understandings, there are very different hypothesis that have been put forward. We will discuss only one of them, but of course, there is more, and new evidence is coming up every other day.

So, new evidence indicates that there are three large systems that interact with each other in order to connect language reception, production, and conceptual knowledge. So, anything to do with language, you will already understand, there is reception, which is comprehension, and there is production, and then, of course, there is conceptual storage or conceptual knowledge, or whatever. So, these three things are primary aspects of doing language, speaking, understanding, or whatever. Now, to subserve these three different purposes, there needs to be a larger system; that is what this idea proposes. So, the first area is Broca's and Wernicke's areas, selected sectors of the insular cortex; the basal ganglia form one system. That is the first system. This system is called the Language Implementation System. So, this is one big area. So, there are three big areas that have been proposed beyond Broca's and Wernicke's areas. So, Broca's area, Wernicke's area, some parts of the insular cortex, and the basal ganglia. together they form the first system, which is called the language implementation system. Now, what does this system do? This system analyzes incoming auditory signals to activate conceptual knowledge.

Then it supports phonemic and grammatical construction and then controls speech production. Of course, Broca's area is there; Wernicke's is there. So, together they perform all these functions. Now, then there is a second system. The first system is anatomically surrounded by another system, which is called the mediational system.

This is the second layer of the entire process. This is made up of numerous separate regions in the temporal, parietal, and frontal association areas. So, this is again a network of areas that are in different parts of the brain. What do they do? These regions act as brokers between the implementing systems. So, they are go-between types; they are connecting organisms and kind of things. So, between the various areas that are part of the implementation system, this area connects them together.

Finally, there is a third system, which is a conceptual system that is a collection of regions distributed throughout the association areas. So, basically, what it means is that, of course, this is a simplified version of the theory. I have simplified the whole thing, but the idea is that these language functions are distributed throughout the brain. And the areas as we understand them today are much bigger, more complex, and more diverse compared to the classical area.

So, a complex neural network that is specialized in language processing is what is now proposed. So, this is the crux of the matter as far as the language areas in the brain go. So, if you recall our debate on the nature versus nurture debate, the role of experience has been one of the bones of contention; that is what the debate is all about: do you need experience or not? So, a strong nativist view understands language as something like an instinct or a special-purpose, you know, mental organ, which has its own neural architecture and its own genetic program. That is how the nativist theory goes. On the other hand, however, we now have a lot of new evidence, as we just saw, and we know that the areas are different; different regions are working together. So, what does it mean basically? If different regions are working together, that means the modularity hypothesis of the nativist theory will not be entirely tenable, because there has to be a network; there has to be a connection between different domains.

So, the visual cortex and the various other domains, including the basal ganglia. this points to an epigenetic perspective, because this kind of connection is created; of course, a lot of it is normal and natural, but a lot of it is also epigenetic, as it depends on the kinds of experiences that we have. So, a more epigenetic perspective has arisen out of all of these understandings, all of these findings in which the human capacity for language emerges both phylogenetically and ontogenetically. So, basically, there are quantitative changes in mental and neural systems. the way we do language, the way language is processed, understood, and acquired depends on more than one brain region, and it is also based on changes in the mental and neural systems. So, this is an ever-changing field where new evidence keeps coming in very often. Therefore, we are updating the entire domain. So, basically, this is where we stand today. That there is a possibility of epigenetics also contributing to the language acquisition processes, based on the finding that a larger area within the brain communicates with one another, helps each other out in a more distributed system. So, that is the end of Lecture 1 on this, where I have given you a brief overview of the language areas and how changes have taken place in the recent past. Thank you.