Fundamentals of language Acquisition

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Week 11

Lecture 052

Lec 52: Brain mapping methods and Milestones in language development

Welcome back. This is Lecture 2 within our Module 11. In lecture 1, we looked at the language areas in the human brain. So, we looked at the basic structure of the human brain and the way the language areas were understood in the past. Those are called the classical language areas, and we also looked at how the understanding of language areas in the human brain has undergone some changes and how we now know that the areas that were proposed before have subregions in them and are more complex than we previously understood. So, as a result of which there has been some new hypothesis that have been put forward. Now, how do we know all of this? This understanding of the finer aspects of the human brain in terms of language functions has, of course, come to us through various kinds of brain mapping methods that have emerged in the recent past, over the last few decades. A lot of changes have taken place, a lot of new machines have been invented, and so on. Before we go into the findings with respect to the neural correlates of language development, we need to understand the brain mapping methods. We will not be able to look at all of them, or let us say, in very great detail, but I will give you a basic idea about some of the methods that are very important for us to understand this particular segment.

And after we have looked at the brain mapping methods, we will look at some of the milestones of language development, and then eventually, of course, we will look at the neural correlates of those milestones. So, there are many different kinds of brain mapping methods available now to the scientific community. There are neuroimaging, functional neuroimaging, electrophysiology, and of course TMS. Within functional neuroimaging, we have three different kinds: one is called positron emission tomography, or PET; then we have functional magnetic resonance imaging, or fMRI, which is the functional version of MRI; and we also have near-infrared spectroscopy, or NIRS, which is comparatively a newer method. Within electrophysiology, we have magnetoencephalography, we have electroencephalography, and there are a few more, like direct cortical stimulation and so on.

Direct cortical stimulation or intracranial recording is not used for children. But we will discuss them very briefly just to give you an idea about the methods that exist, and at the end, we will talk about transcranial magnetic stimulation. So, functional neuroimaging techniques, such as PET and fMRI, are two examples of these techniques. In PET, it tracks the distribution of a radioactive isotope through the blood vessels of the brain. Both of these machines track the movement of blood to the brain. So, in the case of PET, they track the movement of a radioactive isotope as it travels to the brain. In the case of fMRI, functional magnetic resonance imaging measures the blood oxygen level, so the BOLD signal, or blood oxygen level dependent signal, is typically manifested as a hemodynamic response function lasting roughly 10 to 12 seconds. So, basically, how the blood oxygen level and the bold signal tell us about the metabolic response of the various regions in the brain is what fMRI looks at, as opposed to PET, which looks at how the blood flow tracked through radioactive isotopes. This is how the machine looks, and the first one, this one, is a PET measure. This is how the PET output looks, and this is how the fMRI output looks.

So, this is how you see the activation level. So, a fully vegetative state is one kind of picture, minimally conscious, fully conscious, and so on. So, there are these differences in the activation pattern. So, depending on where the radioisotope moves, those areas will be marked as active regions in the brain. Because the basic idea here is that if the brain is working when you need it to function, the metabolism rate will go higher, and for a higher metabolism rate, you need more oxygen, which will be supplied by the blood flow. So, that is why these techniques are blood flow dependent techniques. So, basically, tracking how the area gets activated. So, as you can see, depending on that kind of method, this is how the final picture emerges. Of course, this is not how the brain looks to the naked eye; this is how the machine picks it up, and a lot of processing goes into it. But this is ultimately what we call data. Similarly, in the case of fMRI, you can see that certain areas have been marked here. So, in the case of speech, these are the areas that are active. In the case of a finger tap, you can see this is one area that is active. While listening, you can see the areas that are active. So, this is how they are marked.

So, these areas are marked based on where the blood flow was going while the function was taking place. So, as a result of this, these methods have been called the sort of vampire theory of the brain because they are dependent on blood flow. So, processing activity—anything, any kind of processing that is happening in any of the regions—it will need, it will lead to increased metabolism. To support that metabolism, you need more oxygen, and that oxygen will be provided by the blood flow. So, this is kind of a very, you know, very circuitous way of getting to the point. It is kind of an indirect method, but anyway the idea here is that blood flow is directly connected with neural activity. And so, if you look at the blood flow, you will be able to understand the idea of the neural activity in a particular region. So, all of these methods are called hemodynamic methods because they are dependent on the blood flow. Now there are some issues; of course, these machines are very sophisticated, and they have been used for research in linguistics in various domains. Now, using fMRI with children has some problems because of various factors; for example, one of them is that the temporal resolution of fMRI is limited.

Neural events happen in milliseconds. So, when you are engaged in any kind of activity, the signal in the brain will trigger the activity in the brain, which will happen for a very short time. So, the firing of neurons does not last for a very long time. But the blood oxygen level changes that they induce are spread over several seconds. So, we are comparing here an activity that spreads over seconds with something that actually takes place in milliseconds. So, there is a loss of, you know, data there. So, in the case of temporal resolution, fMRI is not a very good idea; that is one big problem. And with respect to children, the technique is such that it needs the patient, the person, the subject who is in the machine; they need to be still. Keeping children perfectly still is a very difficult scenario. So, it is as a result of which these kinds of techniques are difficult to administer with children.

And also this device produces loud sounds; loud as in for an infant, it will be a loud sound—not that loud, but for infants, any kind of sound will be problematic, and for them, it is quite loud. So, it is necessary for somebody, either the experimenter or someone else, to shield the infant's ears while delivering the sound stimuli because it will create a lot of difficulties. So, these are problems because of which fMRI is not used that often, or it is not a very commonly utilized tool, but it is a possible tool. So, that is about fMRI. NIRS is another term for near-infrared spectroscopy.

It measures the cerebral hemodynamic response again in relation to neural activities. Now, this utilizes near-infrared light to measure changes in the blood oxyhemoglobin and deoxyhemoglobin concentrations in the brain. So, here its method is slightly different, using near-infrared light to look at the oxygenation and deoxygenation of the human blood hemoglobin concentration in the brain. Total blood volume changes in various regions of the cerebral cortex in response to the various kinds of tasks. So, this system can determine the activity in specific regions of the brain by continuously monitoring the blood hemoglobin levels. It is a similar kind of machine, but here they check the hemoglobin level, right? Hemoglobin levels have a direct connection to oxygen levels, and you know all of that. So they are similar. Now, if you compare these, in the case of NIRS, one good thing about NIRS is that co-registration with other testing techniques such as EEG and MEG is possible. So, there is a co-registration that is possible. But the limitations of NIRS are similar to those of fMRI because it does not provide very good temporal resolution, as we have just seen that mental processes occur in milliseconds.

So, it is a very short-lived time, but by the time the blood oxygenation happens and we get the signal, it goes over seconds. So, there is a time lag. So, that is why temporal resolution is not very good; that is one kind of story. The other type of machines that we have is in the domain of electrophysiology. Now, neither PET, fMRI, nor NIRS map the brain activity directly, but through the metabolic consequences of the brain activity.

In contrast, electrophysiological techniques bring us much closer to neuronal firing because they directly pick up the electromagnetic signals from the brain as it occurs. As neuronal firing happens, the signals they emit are picked up by the brain. So, that is why it is a more direct method compared to fMRI and other hemodynamic methods. So, one of them is direct cortical stimulation. This is not typically done with children.

Non-clinical participants do not get used for this. This is typically used for patients with epilepsy and other conditions. So, before epilepsy surgery, direct electrical stimulation is often used. So, the first of these kinds of studies was carried out by Penfield in the late 19th century, a very, you know, pretty old study. He mapped the functional organization of the exposed cortex in epileptic patients prior to removing the epileptogenic areas, which are basically the areas that are responsible for epilepsy. So, what happens in epileptic surgery is that if they have to go for surgery, there is pre-processing that occurs before the surgery. Because they will be removing certain parts of the brain in the surgery. Now, while removing that part of the brain, the doctors need to make sure that by removing that part, they are not hampering other functions like language. So, often they carry out certain kinds of tests to check if the area surrounding that area is responsible for language.

So, that is when it is utilized. So, what happens in this case is that there will be electrodes with a very minute amount of electrical impulse passing through the open area of the brain. So, the cortex is exposed, part of the skull is removed and the brain is exposed and that is where the electrical stimulation will be applied. So, in one such case, an electrode was introduced into the cortex of the superior surface of the anterior temporal lobe. Superior is the upper part; so, there is nothing about qualitative marking here. The superior surface of the anterior temporal lobe and a gentle current was switched on.

The patient exclaimed, "Oh, a familiar memory in an office somewhere! I could see the desks. I was there, and someone was calling me—a man leaning on a desk." This looks like a person describing a scene. Remember, there was no scene like this in front of anyone. All they did was pass a very minute amount of electrical stimulation in the open area of the cortex. That is the area that we talked about, and when that area was electrically stimulated, this is what the person said. So, this is one of his studies. So, following Penfield, many others have also carried out similar kinds of studies. Another very important study; it is quite a landmark study, they did this kind of experiment. The protocol of the study was that line drawings of familiar objects were projected on the screen at 4-second intervals. Subjects had to name them using a matrix sentence: This is a tree, this is a table, this is a chair like that. So, "this is a…. ." is the matrix, and they have to name it. So, the object is there on the screen, and they have to name it. Subjects were 117 patients with epilepsy; as I said, all these were carried out only on patients; no typically developing person would be going through this. In our initial data, all the information in neuroscience, whether it is about language or other mental functions, has typically come from aphasia and epilepsy patients. When you talk about older data, we are always talking about the patient data, right? So, in this case, we also have epilepsy patients; at the onset of some of the slides, the experimenter stimulated some of the predetermined points on the exposed cortex. So, the stimulus is already ready just as they are about to begin, the current is introduced.

And each site was stimulated three times; patients' responses were recorded for each of the responses. What did they find out? In the vast majority of cases, stimulation disrupted naming only in a few discrete sites. So, in certain domains, naming in certain areas was disrupted when the electrical stimulation was applied. In 67 percent of patients, two or more such sites were detected, usually one in the frontal cortex and another in the temporal or parietal cortex. The precise anatomical location of the sites responsible for naming varied greatly among subjects. This is one of the most important findings of this study. Because there are some broad areas that were found to be responsible for naming, if that area is electrically stimulated, the patient's naming will be affected; if not, then if they are not affected, that means that area is not responsible. So, that is why they found larger areas like the frontal cortex and some areas in the parietal cortex and temporal cortex. However, what is more important is that those exact areas will differ across patients. So, it is not that every human being has the exact same kind of area for the exact same kind of functions; that is the finding.

This suggest substantial variability across the population. Another kind of brain-mapping technique is called intracranial recording. This is used to measure neural activity at the level of a single cell, but more often they are used at the level of cell assemblies. So, a small area, a small region will be focused on, and this is the method; one method, one of these methods, is called electrocorticography. They will be mapping; they will be taking the signals from inside the cranium.

So, intracranial and extracranial; intracranial means inside the cranial cavity, which is inside the skull, directly from the brain. This involves placing a high-density multi-electrode grid over the exposed cortical surface. This measures the local field potentials of cell assemblies. So, the region where there is a cell assembly is a particular concentration area that can be measured with sub-centimeter spatial resolution and millisecond temporal resolution while the patient performs various linguistic tasks. This is what the electrocorticography thing looks like. So, this is a grid. This is again not an actual picture of any actual person. This is for representative purposes only. So, let us say this is the grid and this is what it is. So, we have the motor area, we have the sensory area, then we have the surgical opening, and this is what we are looking at. So, the entire grid is what we are looking at in the entire region.

So, the resolution will be spatially and temporally quite high So, how does that entire area function within that area? What kind of, you know, which area, which sub-area is doing what? That is what will be picked up. So, the signals will be picked up as the person is doing some kind of a linguistic task. Again, the data will be typically from our epileptic patients. Now, we move on to the electroencephalography, which is EEG; this is how the machine looks. It is like a cap, of course; now it comes in various other shapes, but roughly this is like a cap with many channels and many nodes, which are basically electrodes that will be put on the scalp. So, there is a method through which it will be attached to the scalp, and it picks up event-related potentials along the dimensions of latency, amplitude, polarity, and topography. These are the things that are our variables. So, simply put, when you are busy doing something, some kind of functions, you know, speaking or playing something, or simply blinking your eyes. The electrodes will pick up the signals from the area that is involved in that kind of function. And that will be amplified through some machines, and ultimately, what we see is a sine wave.

And depending on whatever the data is, we will be able to correlate it with the functions. So, ERP, which is part of the EEG, reflects electrical activity that is time-locked, time-locked to the presentation of a specific sensory stimulus, for example, syllables, words, or a cognitive process, or whatever. So, time locked, as in exactly the time when the stimulus was presented, at that time the kind of signal that the brain is giving out is what our data shows; that is what the ERP will be; that is the ERP we are talking about. So, the activity of neural networks firing in a coordinated and synchronous fashion can be measured with this machine. Voltage changes occurring as a function of cortical neural activity can also be detected. ERPs provide precise time resolution; they are very good for temporal resolution, making them well suited for studying the high-speed and temporally ordered structure of human speech. So, EEGs are very useful for studying human language because of their very good temporal resolution. This can also be carried out in populations who, because of age or cognitive impairment, cannot provide overt responses, because here you do not have to do anything. For example, you can just be sitting with a cap on, looking at some pictures or, you know, even linguistic stimuli on the screen. So, as you are reading them, you are just looking at them; your brain is processing that information, right? So, that processing will be picked up by the machine itself.

So, you do not need to do as such anything you know overtly do anything. So, that is why this machine is useful. Even with children, you just put the cap on, and it is safe; it does not harm them or cause any inconvenience. So you can see how happy the child is.

This is, of course, a picture that I have taken from the web. So, this is why it is very useful to be used both with the aged and with the old; you know, all kinds of situations it can be utilized in. But the only problem is that the spatial resolution is slightly limited in this kind of thing. So, the main ERP components that we will typically refer to when we talk about language processing. Of course, there are many, but the most important ones are N 400. N 400 basically refers to the negative; as I said, this is the data.

The final thing that the output gives you is a sine wave. So, in this kind of N400, it is the negative-going peak at 400 milliseconds that is what N400 is all about. Now, this is the peak we will see in response to semantic anomaly. So, when a sentence is semantically anomalous, for example, "the man bit the dog." So, the dog biting a man is fine, but a man biting a dog can also be possible, but there is something off. So, in that case, you might find, or let us say you hear, a sentence like "I take my coffee without sugar and sky.

" Until without sugar, things were going fine, but the moment you hear or look at the word "sky," your brain will give you the N400 impact; the machine will give you the N400. That is what N400 does. Then we have P 600 another important indicator of processing. This is a positive going peak reflecting syntactic processing and reanalysis at 600 milliseconds.

Then we have MMN, mismatch negativity. It is a negative-going component. This is seen when a listener detects a change in the repetitive sequences of sounds. So, this is often used to investigate phonetic comprehension in children. For example, if you are hearing a lot of sounds one after another, at one point there is a certain foreign sound.

the sound that is not a part of your own language. In that case, we might see this M M N signal. Then, LAN, left anterior negativity it is used for early syntactic processing generally in case of grammatical error. So, these are some of the main variables that we see in the case when we use EEG. Then, another machine called MEG, magnetoencephalography. This is another brain imaging technique that tracks the activity of the brain with exquisite temporal resolution and very good spatial resolution.

This has a kind of method which is called a superconducting quantum interference device. The sensors located within the MEG helmet are similar to a cap or a helmet-like structure. This measures the minute magnetic fields associated with electrical currents produced by the brain while performing any kind of task; it can be sensory, motor, or cognitive. So, it is kind of similar, but this picks up the magnetic fields and fluctuations in the magnetic field while the brain is doing things. So, this allows for precise spatial localization of the neural currents responsible for the sources of the magnetic fields.

Phonetic discrimination in newborns and infants in the first year of life has been extensively studied using MEG because these are all harmless kinds of tools and do not cause any kind of inconvenience to the children. As a result, many studies on infant language acquisition have used EEG and MEG. So, latest studies employ sophisticated head-tracking software as well as hardware that allows correction for infants' head movements and examine multiple brain areas in infants as they listen to speech. So, these are very sophisticated machines that are being used today: MEG and EEG both; and, as I said, they are completely safe and noiseless. It is very safe to use with children and, as a result, quite common. The final machine that we are talking about is transcranial magnetic stimulation. Now, what this does is that it is neither something where you have to open up the skull nor are you putting on a cap, but it is a very strong magnet—not very strong in the sense that, of course, it has to be used with normal human beings as well. So it creates a magnetic field from outside the brain. So, it alters the organization of neural activity in a target cortical area by projecting a magnetic field through the overlying skull. So, from outside the head, it is not attached to the head; it is outside, and then it can apply, as you can see from the machine, it applies a magnetic field.

So, it literally messes with your head. So, it creates and alters the neural activity. The temporal resolution is in the order of milliseconds, and the spatial resolution is in terms of millimeters. So, it's quite a good resolution. The parameters of the protocol, mainly the frequency of pulses, can be adjusted so that one can either facilitate or support the operation of the target region. So, it is a very sophisticated machine because you are applying this from outside; you are creating a different kind of magnetic field there.

So, it can depend on what you are looking at: are you helping that particular region's magnetic field by, you know, increasing it, or can you also change the pulse in order to suppress it? So, it can be both positive, or it can be utilized in both a positive way, as in facilitating or inhibiting, depending on your research question or what you are looking for. And then, depending on the function that the human brain is carrying out, that is what our data is. So, these are the various kinds of techniques that are used for language processing studies as well as for language acquisition studies. As far as infants are concerned, more use of MEG and EEG is seen as opposed to the other ones. In the case of typical children, if it is an epileptic patient's case, of course, we have the other machine and other possibilities, like an open brain kind of probe, but that is only in the case of epileptic patients. So, before the pre-surgery processes, that is when we see them. But otherwise, in the case of normal children, we do not use them; only the EEG and MEG are typically used. So, these are some of the most important tools. Now, when we look at the basic milestones of language acquisition among children, there are some very important milestones. We have already looked at them before, but just to brush up on them. So, in the very initial stages, the first 6 months, we have universal categorical perception; then we have perceptual narrowing, followed by the first signs of word comprehension, followed by word production, and then, of course, we have the development of grammatical rules and larger sentences, and so on.

So, in the very beginning, in the case of infants at the start of their lives, we have seen that they are capable of categorical perception across languages. So, it is not only one language, but they are able to, if you recall, in the beginning, we have seen that in the phonological section, where infants are capable of distinguishing between sounds that are non-native as well. So, they can distinguish between native and non-native sounds, they can distinguish between their mother's voice, other female voices, their own language, other languages, and all kinds of things. So, the perceptual abilities are very high; the acuity is very strong. So, it is called nearly universal; all infants are capable of distinguishing various kinds of sounds. So, in the beginning, it is very strong. However, this capacity is dramatically altered by language experiences starting as early as 6 months for vowels and 10 months for consonants. At 6 months, infants begin to organize speech sounds into categories based on phonetic prototypes. We have already seen that after some time, the ability to distinguish between sounds across different languages, even non-native languages, diminishes. Because the idea is that as they learn and are exposed to more input from their own language, their phonetic categories and phonemes get created in their brain, resulting in good exemplars of that category.

And around that, you have the native language magnet theory we have talked about. So, around that prototype, they create their categories in their own language. So, it is the most frequently occurring phonetic unit in their language, which is the prototype. So, reasons for the change in infants' perception between 6 and 12 months of age have been attributed by various researchers to what is called implicit learning because of environmental input. So, early exposure to speech induces an implicit learning process that reduces the infant's initial ability to hear distinctions even between foreign language sounds. So, as the ambient language gets ingrained in the brain, they create their prototypes and stop recognizing the other languages. The second half of the first year is very important because this is a very sensitive period for speech learning. So, the idea is that if these infants are exposed to learning around this time, does it mean that if you expose them to another new language, they will learn? This was the idea that Kuhl and her colleagues examined. So, they exposed American infants to Mandarin Chinese in the laboratory between 9 and 10 months of age and had a very interesting finding that infants learned if exposure occurred through interaction with a human being. So, children at this level can learn a new language at this stage if they are exposed to it by a human being, not by some kind of robot or something. So, if it is through television or an audio tape with no live human interaction, then they do not learn.

So, this actually gives us the idea that they are learning. And this gives you evidence of the learning, reinforcing the phonological structure of their own language. And that is why, by the end of the first year, their brain no longer exhibits the universal capacity for all languages. Now, it is primed to acquire the language to which the infant is exposed. So, this is the first stage of learning, and then this will, you know, give rise to the second stage.

This narrowing, perceptual narrowing, now gives rise to the next. So, how learning produces this narrowing of perceptual abilities has now become a focus of intense study because it demonstrates the brain's shaping by experience during a very critical period of language acquisition. That learning actually plays a role is what Kuhl and her colleagues have shown: initially, it is all they are able to perceive— all kinds of different sound distinctions—but over a period of time this changes, and that perceptual narrowing is dependent on their implicit learning. It is not conscious but implicit learning. So, major changes in frontal lobe activity seem to coincide with this particular stage of language acquisition.

This is also called the watershed, you know, an 8 to 10 month watershed. Because major changes happen not only due to this perceptual narrowing, but also because of comprehension, communication, imitation, and reasoning. So, the frontal lobe activity is very high at that time. So, there are a lot of coinciding things that are happening. The next stage, which is the comprehension stage, generally occurs between 8 to 10 months, while word production typically begins at 11 to 13 months after this. So, this is called the vocabulary burst, which is a rapid acceleration in the rate at which new words are learned.

Now, this is called a vocabulary burst, and then we also have another rapid burst of grammatical development much later, at 20 to 30 months. So, these are the stages that follow the first year, and then after this, we have this particular stage. Now, around the same time, there are some changes in the neural organization as well. So, the period between 8 to 10 months is what we have just seen is called a behavioral watershed because many other things they learn are characterized by a marked change in or reorganization of different domains. In linguistic terms, rapid growth in speech perception, production, and word comprehension occurs. Behaviorally, what happens? Memory and categorization, imitation, joint reference, and intentional communication develop. So, at the same time, you see there are many things happening. So, this set of correlated changes has been explained by a very famous, publication where it is proposed that the achievement of adult-like patterns of connectivity and brain metabolism occurs at that time. During this time, as we will see in the next segment, certain kinds of activities and connections that are built up almost resemble the connectivity of adult human brains, this develops around this time. So, the idea that was put forward is that this connection is developing simultaneously; when you see this kind of linguistic and behavioral output, they are probably correlated. Causation has not been proposed, but correlation certainly may be. So, it particularly involves the frontal lobes. Again, the period between 16 and 30 months sees a series of sharp non-linear increases in expressive language. This is when you see an exponential increase in both vocabulary and grammar. This is what happens one and a half years later. So, 16 months onward to 30 months, there is a sharp increase in language ability again. It is estimated that a marked increase in synaptic density and brain metabolism also takes place around the same time. Synaptogenesis is a very important aspect of brain development that seems to occur around the same time as the burst of grammatical categories, longer sentences, and so on. Thus, a possible link was proposed between this series of behavioral bursts and the neural changes. However, this has been revised, but it still remains a very important hypothesis. So, this is where we stop for the second lecture. Thank you.