

Fundamentals of language Acquisition

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Week 11

Lecture 054

Lec 54: Neural activation pattern for bilinguals

Hello and welcome back. We are in Module 11 now. In this module, we are looking at the relationship between brain development and concurrent language development. So, until now, through the last three lectures, we have looked at first language acquisition and tried to understand how the developmental stages of language co-occur with the developmental stages of the human brain. We looked at the developmental stages of the prenatal brain and then the postnatal brain during the infancy of the children. How the major developments and major milestones that are crossed seem to correlate; they co-occur, though we are not exactly sure whether there is a cause-and-effect relationship between them. So, for example, we have seen that some major milestones, like the burst of naming, word naming, or similarly, after some time around 20 months onward, the burst of grammatical categories seems to co-occur with certain important developmental milestones of the human brain as well. So, in this regard, we have looked at synaptogenesis, which is the creation of synapses that starts just before birth and continues; however, the largest amount of synapses is built around the 8 to 9 months gestation period to the early part of life. Of course, this goes on throughout our lives, but it kind of tapers down and the rate is not that high. So, synaptogenesis was seen with respect to the language development of certain types, and we also looked at the frontal lobe metabolism, which is considered to be another important milestone in terms of brain development, and this also seems to co-occur with another watershed moment in language development.

So far, we have talked about this. We have also looked at, and we know that perceptual

narrowing happens around the first year, from 10 months to 12 months; children's ability of categorical perception narrows down. So, in the beginning, they are able to distinguish between sounds in all kinds of languages, including their native language as well as other languages. However, around one year of age, that capacity seems to narrow down, which is called perceptual narrowing. Now, on the surface, perceptual narrowing might look like some sort of developmental regression. Regression, as in regression, is the opposite of progress. So, it looks like we are going back. So, initially, they started their life with a higher capacity for distinguishing sounds of various kinds. So, speech sound versus non-speech; within speech, also, various kinds of subtle differences they were capable of making, but after a point that seemed to go down. So, does it mean that there is a regression happening? As per scholars, that is not exactly how it should be looked at.

Perceptual narrowing actually indicates more efficient processing of the salient environmental cues. For example, that is the time when we talked about the various kinds of environmental input that the child learns; we looked at implicit learning in the previous lectures where the child, the environmental input, and linguistic input help them narrow down the appropriate phonetic and phonemic contrasts in their own language. So, that narrowing is important in order to focus more on the native language. So, that is what the scholars are saying: that this is actually not a regression, but it is sort of a more efficient handling of the task at hand. And interestingly, there are also a lot of parallels with this perceptual narrowing along with language. So, like within language, we have already seen that narrowing happening, but this is not something you know is essentially only a linguistic matter. There is perceptual narrowing that happens in other domains also. So, for example, that is there in the case of face recognition. So, in the initial stages, children and infants are able to recognize, you know, differentiate even monkey faces, but as they grow older, around the same time when perceptual narrowing in phonemic distinction happens, they also experience perceptual narrowing in face recognition. Similarly, music and multisensory audiovisual perception, and so on.

So, there are various domains in which perceptual narrowing occurs. So, this is part of a larger developmental trajectory within which we have to look at this particular feature. Now, let us have a quick recap of the various stages of development that we have already looked at. In the early stages, the brain produces a lot of neurons, and connections between them, called dendrites. So, there are a large number of neurons that we start with and a large number of connections as well. Over time, many of these neurons die, a process called pruning; there are also many other names that we saw yesterday. And this connection, you know, death, neuronal death, is also called dendritic pruning. Simultaneously, we also looked at the myelin sheath that comes in, that starts building up

and is a very important aspect of the development of the human brain because this helps in better transmission of electrical signals along the axon. So, these things have already been discussed. Now, there is another way of looking at the development of the brain.

Of course, we started with cell generation, then cell transportation, and then building up the connections, and so on. But there is another way of looking at it, which is which part of the brain gets built first and how it progresses. So, following Best, we will stick to this particular way. So, it starts from right to left, then from primary to secondary to tertiary regions, and finally from the basal area to the cortical area. So even within the cortical area, we have discussed this before, the prefrontal cortex is one of the last areas to be built. So, the sensory cortex is built first, and then we eventually progress. So, the current brain imaging studies also corroborate this hypothesis; hence, we will stick to this. So, in infants, sensory cortices develop earliest in life when we are talking about the cortical regions; the sensory domains and sensory areas develop first. This is followed by the development of sensory bridges in the parietal lobe and the motor cortex in the frontal lobe. The most anterior part of the brain, the prefrontal cortex, develops the latest among the other parts. So, in the case of brain structure, the anterior means the frontal part; anterior is opposed to posterior, which is the back portion. So, anterior, as part of the brain, typically refers to the prefrontal cortex, which is the last area to be developed. So, changes keep taking place after this as well, but they do not happen in such a visible way. There are more of a software update than a hardware build. So, hardware building happens this way, and it is kind of complete in the early part of life.

Now, these stages of cortical development are also important for word acquisition and the later processing of those words. Early words, so why is that? Because we have already seen that after the child is born, the brain is still developing, and now, around the time when they are one year old, they are already capable of comprehending words as well as beginning to speak in words. Now, at this time brain is still developing. So, as a result, it is very easy to see the words that they learn in the first part of life; like the first part of word acquisition, they will typically be dependent on the sensory-motor cortex to be processed. And the words that they learn later, there are chances that the prefrontal cortex will also play a role. So, that is what we are getting at in this particular segment. So, early words of infants might show dependence on those cortical parts that develop early, around the same time and the later learned words in the later developed area, which is the prefrontal cortex, as we have just said. So, this has been investigated not only in monolinguals but also in bilinguals. In the case of bilinguals, we are looking at the question slightly differently, but let us start with the monolinguals to give you a basic idea. So, now the main question that was asked is: If there is a parallel between the age of acquisition, that is, language acquisition, and the brain's developmental stages, this was a hypothesis that the initial stages of the words may be dependent on the initial structure of

the

brain.

So, that is the hypothesis: is there a mutual dependence of this sort? In other words, how does the processing of one's native versus second language reflect the dependence on different areas of the brain? Now, why is this important? This is important because when we talk about a second language, we are typically talking about a language that comes into your repertoire after the first language is already in its place. So, there are particular age brackets that we typically take into consideration. The typical cutoff will be 3 years; however, we do not really have very airtight compartments anymore, but around 3 years onward, this is a spectrum. So, after 3 years, we can safely say that if you are learning another language after 3 years of age, then it is your second language. So, as a result, it is very easy to see the first language and, you know, the region of the brain where it is processed, as well as the words of the second language and where it is processed in the human brain. So, these are the main ideas that we were talking about. So, native language processing is, you know, that the sign basically means this has a correlation with the areas that develop earliest in infancy because the native language is the first language that you learn. So, that those words will be processed in those areas. Similarly, L2 comes in any time after 3 years of age. Now, when we are talking about L2, we have to remember that we are talking about both child and adult L2 learners.

We will see the finer distinctions later in the section. So, L2, as of now, means both child and adult L2. So, L2 that comes in after 3 years of age can be processed in those areas that develop later. This is the question. Now, this probing this question will also answer the question of the sensitive period for language learning, which we have already discussed before that the critical period hypothesis which is also called sensitive period now. And if we understand this, if we see a direct correlation between brain areas and the kinds of developmental trajectories that language learning follows and whether they are similar between L1 and L2, then we will be able to answer a lot of questions in this domain. So, in a second language, it has been reported that L1, which is the first language AOA before about 6 years, or an L2, which is after 7 years, are represented differently in cortical areas; 3 years and 4 years are slightly difficult. So, most of the researchers have taken a break-up after 6 or 7, but when we define a second language, we typically go after 3 years. And there are at least two major factors that have been pointed out when we talk about the localization of L1 versus the localization of L2 in the human brain. There are two factors that have been put forward.

This is a domain that is rich with literature; many different kinds of perspectives have been explored, and out of all that research, there is typically an agreement that age of acquisition and proficiency level play a part in where in the brain the L2 will be

localized, specifically regarding the functional localization of which part of the brain will take up that responsibility. There is a correlation between the age of acquisition and proficiency level. Age of acquisition means the distinction between early bilinguals and late bilinguals, and in terms of proficiency, we typically look at low-proficient versus high-proficient bilinguals. So, bilinguals are not a mono, homogeneous, or monolithic kind of structure. There are different kinds of bilinguals.

So, we will stick to the age of acquisition and proficiency. Now this particular question, this particular domain, has been approached by connecting it to word processing. This early development of sensory motor areas and later development of the frontal lobe functions are the main variables that we have typically been looking at, and words can be processed in different areas depending on when they are learned. So, if the words are learned early in life versus being learned later in life, we would expect them to be processed in different areas of the brain. And this is applicable not only to bilinguals but also to monolinguals. Children, when they are learning words in their word-learning stage, tend to learn certain words in the beginning and certain words that they will learn much later in life. For example, orangutan is not a word that will typically be in the vocabulary of a 1-year-old or a 14-month-old child, but the toy will be; something like that. So, that is also visible. Keeping this in mind, we will now discuss many research findings that have been carried out. One of them, one of the older ones, is by Morrison and Ellis, 1995.

They carried out a lexical decision task with monolingual participants. Now, what is the lexical decision task? The lexical decision task is a task where there will be some sort of input stimuli that the participant has to look at and decide whether it is an acceptable word in that language or not. So, for example, let us say that this is a word. Now, if I have something like this, this will be the task. Now, in the first case of the lexical decision task, both words and non-words are given. This is the second example; this one is a non-word; they are called non-words. Nonwords are created by slightly manipulating an existing word. So they are maximally similar to an existing word with minor modifications. So, the modification here is the final phoneme. And when they are performing the task, they will see words as well as non-words in a randomized order.

They will have to check whether there will be a no response or a yes response. So, this is a word; this is not a word; this is a non-word. Now, this task is one of the fundamental tasks of our language processing research. So, depending on what your probe question is, there will be different kinds of designs. So, in this experiment, they wanted to see if the age of acquisition plays any role in the processing speed of the participants.

So, the non-word, the "no" responses were actually not our target responses. Target responses were the "yes" trials. So, all the words that were that would elicit the answer yes were the actual trials. The "no" was just given there as part of the experiment. Within the "yes" response set of words, they were divided into either those words that are learned early or those that were learned later; that was one set.

The other set of words was divided in terms of their frequency. So, how frequent are those words in the child's vocabulary? What they found was the result reflecting the effect of AOA, AOA as in age of acquisition but not that of frequency. So, the age of acquisition depends on whether they were learned early; they were reacted to much earlier compared to if they are learned later. But frequency did not have a variable, so frequency was not a variable that yielded any results, but AOA proved to be an important variable. So, these studies paved the way for many other studies that followed them depending on where in the spectrum they fall. Similarly, another study was carried out by Hernández and his group. They found the effect of both AOA and frequency in picture naming. So, picture naming is a production study, while the LDT lexical decision task is a comprehension study. So, there is a difference that we see in terms of whether it is comprehension versus whether it is production and what variable will be important in each case. Similarly, there are other studies; yet another study showed that words learned in early childhood led to activity in Heschel's gyrus and other brain areas responsible for speech sound processing.

So, this is one particular area where early words are found to be processed. Words learned later relied on brain areas in the lower part of the inferior frontal lobe. So, this is exactly what we were talking about. So the frontal lobe, specifically the prefrontal cortex, is developed later. So the words that were learned later were seen to be processed in the inferior frontal lobe. Inferior and superior are the top part; inferior is the part below. So that area was responsible for processing the words that were learned later. So this area is basically reflecting the effortfulness of processing. So, if you need more effort to process something, actually a large part of the prefrontal cortex is dedicated to control mechanisms, executive function, attention control, and so on and so forth. So, anything that requires voluntary control, some amount of a control mechanism, and some amount of effort is processed there.

So, that is exactly what they found: the words that were learned later were processed there. This pattern of processing showed a parallel to the brain's areas of development, where sensory cortex development precedes prefrontal cortex development and their

language counterpart. Task-wise difference also. So, reliance on sensorimotor processing changes as a function of AOA. So, depending on when the words are learned, what is the age of acquisition will vary the reliance on the sensory motor cortex.

So, if it is very early, AOA is very early; then there is more reliance; if it is later, there will be less reliance. That is how it works. So, as brain maturation expands to the frontal lobe, individuals process information differently. Deprivation in the early years affects some aspects of language more than others, as we have already seen; when you talk about the critical period, deprivation in this case will refer to those words that were not learned in the early years. So that is why they were deprived of the sensory motor cortex processing.

So in those cases, some certain parts of the grammar and phonology will be affected, but not the entire language. So what this means is that different aspects of language are differently sensitive to age. Not all aspects are sensitive, but certain aspects are sensitive to age. Now, neuroimaging studies on the bilingual brain have looked into this aspect as well. We have already discussed some neuroimaging techniques. So, we will discuss some of them now. Some of the studies using those techniques will be discussed. One study, for example, using PET positron emission tomography, showed that the native language led to a wider area of activation, while later languages involved a very small area compared to it; thus, the native language, as the first language, was processed over a larger, wider area in the brain, whereas the second language involved a smaller domain. Now, the task they used was listening to stories in their native language and in their L2. The participants were Italian-English bilinguals; they had to listen to a story.

Then, similarly, there are also fMRI studies that followed. In one such study, they asked a group of early and late bilinguals to say 'in their heads' what they did the day before, as in just remembering, thinking, you know, thinking without speaking, without saying anything, just thinking about what you did the day before. Now, there were different kinds of prompts given; one cue was the morning or afternoon. So, what did you do yesterday morning around this time, or what did you do in the afternoon? You just have to think; you do not have to say anything. And then, while they are at it, what was probed was the area of interest, as in exactly the area of the probe area. So, in the brain, you already have a predetermined area that you will be focusing on.

So, if you are looking at the entire brain, typically we do not do that unless that is your research question; we pre-decide an area of interest. So, you want to see which area of your brain is activated when we are thinking about a certain action. So, I will propose that, let us say, Wernicke's area will be more active compared to Broca's area, something of that sort. So the area of interest is already decided as part of the experimental design.

So in this case, the areas of interest were Broca's area and Wernicke's area.

Now, in the case of Wernicke's area, what they found was overlapping activation, overlapping activation as in overlapping for the languages. So, overlapping activation pattern for both languages was noticed for both early and late bilinguals. So, in case that is what happened in Wernicke's area, in the case of Wernicke's area, but in the case of Broca, BA is Broca's area, and WA is Wernicke's area. So, in the case of Broca's area, early bilinguals showed overlapping activation, but in the case of late bilinguals, there were two clearly separate but adjacent areas. So, there is a very clear separation between early and late bilinguals in terms of their processing language in the case of Broca's area.

So, that is what we see in terms of the age of acquisition in the case of bilinguals. This suggests that when reciting to themselves, early and late bilinguals invoke neural systems that overlap in the area of comprehension, but they do not overlap in the case of production. So, because Broca's area is more dominant in the case of production. EEG studies were also carried out. So, we are looking at one representative sample from all the different kinds of studies that have been carried out. Of course, there are many more. So, in the EEG, we typically look at N200, P600, and N400 effects. So, in this case, the researchers wanted to find out if these components will differ among bilinguals differentiated in terms of AOA. Simply put, if there is a difference between early bilinguals and late bilinguals in terms of their N200 and P600 effects. That is the simple question they had. Now, subjects, what was the task? Subjects were told to read sentences that were designed to go wrong at the bolded word.

So, they used grammatically wrong sentences in order to see the effect because, if you remember, we talked about P600, where syntactic errors will be processed; the P600 effect is more often seen if there are syntactic errors. So, that is why they use this kind of sentence. The scientist criticized Max's proof of the theorem, which is what this kind of sentence was created for. What they found was that early negativity was reduced in all learners, but late learners did not show reanalysis of the sentence, which is P600.

So, reanalysis was not observed. Early learners between the ages of 1 and 10 showed indications of reanalysis at a later stage. The evidence of later components reveals that early learners perform reanalysis like monolinguals. So, there is a parallel between early bilinguals and monolinguals. Early bilinguals are those people who have learned their second language early in life. So, their processing in terms of the localization in functional localization in the brain are similar to that of a monolingual. Monolingual, in this case, means for us native speakers of a language. So, the way you process your L1 is also the way you process your L2 if your L2 has been learned early in life; that is what the conclusion here is. A follow-up study again looked at late learners

and native speakers of English; they also have similar kinds of findings. So, late learners did not show early negativity; late positivity was spread across a large area of the brain and extended over a longer period. So, regarding the differences between early and late learners, there are many other studies that also confirm this. So, late learners, basically what all of this means is that late learners use a different mechanism to process grammatical information compared to native speakers and early learners.

And between early learners and native speakers, there is a lot of similarity. That is what the main finding has been so far. Also, second language learners, even early learners, may show a different pattern of processing as compared to native speakers as well. Detecting errors, for example in grammar in a second language, relies largely on later analysis.

So there are finer distinctions. A broad distinction is that early bilinguals process their L2 similarly to their L1. And late bilinguals process differently, but bilinguals as a whole also differ from native speakers in certain grammatical categories of processing in terms of their signature neural signature. So, there are differences even among early learners. So, then there are, of course, fMRI studies that have also been carried out. And they found that late bilinguals showed increased activity in the prefrontal cortex near Broca's area and areas associated with speech sounds. Early bilinguals did not show any differences in the brain's metabolism. Again, there is another study on gender marking fMRI with Spanish monolinguals. The task was to judge whether the nouns presented to them were masculine nouns or feminine nouns because Italian has grammatical gender like Hindi in India. So, there are certain rules as to where the nouns will be, which will determine which will be feminine and which will be masculine nouns. So, for example, they have regular and irregular nouns. In the case of regular nouns, the words ending in "o" will take masculine nouns, masculine gender.

So, this is the word for "car" in Italian. So, if it ends in "o," then it is a masculine gendered word, whereas all the words ending in "a" will be feminine. So, "casa" is the word for house; this is a feminine noun. But the more critical part comes in this language, where there are certain irregular words that do not follow this rule. So, for example, all these words that end with this can be either masculine or feminine. So, you see the fountain, so fuente and puente both end in /e/, but word "fuente" is feminine, and "puente" is masculine. So, this is the problem. So, these are part of the list of words that are called irregular words in this language. Now, the task was that this particular experiment used stimuli that had an equal number of masculine and feminine nouns, and they were also equally divided into regular and irregular nouns. What did they find? Results showed that irregular nouns have increased activity in three different brain

regions. The anterior insula, as well as the superior and inferior portions, is Broca's area and the anterior insula.

So, these are all connected to articulation. Additionally, they found increased activity in these areas. So, the anterior cingulate gyrus, which is related to increased cognitive effort, is where you are trying to make sense of the amount of effort needed to disambiguate what is happening here. So, because of the irregular words, there is no problem for regular words. So, after the experiment, they actually interviewed the participants and asked them what they did, how they figured it out, and they were actually searching for the determiner to fit in, and then they made a choice. So, in their head, they were speaking those words without any verbal output; they were imagining the words.

So, whichever kind looks correct, that is what they chose. So, this basically means that the speakers were mentally creating the noun phrases in their minds with the determiner. So, all of these needed more cognitive effort, and that is why we saw the activation in those regions that are responsible for tackling difficult decisions. Many other studies have been carried out on similar topics, and they typically involve a similar stimulus, focusing on the division between early versus late learners, with comparable findings in most cases. So, in this study, early learners also showed increased activity in the inferior part of Broca's area, like monolingual Spanish speakers, but late learners showed a different area altogether, adjacent to an area that is more dedicated to the retrieval of meaning. So, basically, what happened is that the gist of the matter here is that age of acquisition turns out to be an indicator of localization of processing for bilinguals.

The age of acquisition also predicts the volumetric changes in the left anterior cingulate cortex. These are more recent findings that bilingualism actually leads to structural changes in the human brain. And in some cases, there are more gray matters; there is an increase in gray matters in certain parts of the brain. Similarly, there are findings in the case of ACC, the anterior cingulate gyrus, which also has volumetric changes with respect to the age of acquisition. So, this is a kind of dynamic; in the case of bilingualism, there is a dynamic relationship between the language, the age of acquisition, the exposure, the number of years that you have spent, and also proficiency. So, there is a dynamic relationship that exists. So, proficiency, on the other hand, which is also a very important predictor, was more relevant for volumetric changes in the right inferior frontal gyrus. So, this is where we end with Lecture 4. In the next lecture, we will carry on with the same topic with respect to proficiency, and we will also look a little bit into control mechanisms. Thank you.