Speech production and speech processing observed

Group Eta

Anusha Gunawardena

Jonathan Krikeb

Nynke Moelijker

Martina Puppi

Sterre Witteveen

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1. Introduction

The ability of communicating with congeners is of vital importance for all animal species. In humans, the most distinctive form of communication takes place by the means of language. The act of communication through language consists of several components: listening, speaking, and one that enjoys special status, for the ability to act out the component can only be achieved through deliberate learning: reading.

Language has been one of the earliest area of research in neuroscience. Remarkably, it was the first cognitive function to give clear indications of hemispheric asymmetry – the prevalence of one hemisphere over the other for the carrying out of a specific activity. For most people, the major language functions are fulfilled by the left hemisphere. However, recent research has proven strict localization to be false, showing that the interaction within the left hemisphere is more dynamic than previously thought. In particular, the right hemisphere seems to contribute emotional context to language, e. g. regulating pitch and tone.

Within the context of this hemispheric differentiation, different brain areas are thought to be responsible for speech production – the ability that allows us to utter words and complex sentences – and speech perception – the mechanism responsible for the comprehension of the words we hear. Broca's area, located in the pars triangularis/opercularis of the inferior frontal gyrus, is traditionally associated with speech production; Wernicke's area, located in the posterior section of the superior temporal gyrus, is thought to be responsible for speech comprehension. However, recent research has hypothesized that these functions might overlap, in particular affecting an involvement of Broca's area during the processing of complex sentences. Functional magnetic resonance imaging (fMRI) has been the preferred method to come to these types of conclusions.

The aim of our research is to make use of EEG to come to a greater understanding of how speech perception and speech production are divided into the two aforementioned areas. EEG data collected from a speech comprehension task shall be compared to EEG data collected from a speech production task. The opercular part of Broca's area (Brodmann area 44) is covered by node F5 on the left hemisphere and by node FC6 on the right hemisphere; the triangular part of it (Brodmann's area 45) is covered by node F8 on the right hemisphere and by node F7 on the left one. We expect node F5 to be more active in speech production than in speech perception, but also be somewhat active during speech production. Wernicke's area (Brodmann area 22) is covered by node T7 on the left hemisphere and by node T8 on the right one. Similarly, we expect to see more activation in node T7 during speech perception, but we also expect some activation during speech production.

2. Background

The discovery of Broca's area at the end of the 19th century was the first clear demonstration that brain functions can be anatomically localized (Bear *et al*., 2001). Thanks to studies with aphasic patients, Broca's area has long been associated with speech production (Wildgruber 1997). A person affected with Broca's aphasia is often still able to speak but will make grammatical errors, repeat himself, exaggerate articulation, and speak in short phrases, using only dominant words, leaving out articles and prepositions (McCaffrey 2011). However, recent research is bringing to light other functions of this area that might be more specifically related to language comprehension, instead of language production. For instance, Caplan (2006) has argued that Broca's area plays a major role in processing syntactic information - which is crucial for retrieving semantic meaning. More specifically, Grodzinsky (2000) found an involvement of the area in the processing of noun phrase movements and wh-movements used in questions.

Keller *et al.* (2008) challenge the anatomy of Broca's area, yet the general agreement remains that language is left lateralized for most people. Such claim is also supported by Whitehouse and Bishop (2009). In their research, they disprove the bias of the relationship between language and spatial memory and show that there is no direct correlation in this brain asymmetry. Takahiro et al. (2011) studied hemispheric asymmetries with the use of near-infrared spectroscopy (NIRS), functional MRI (fMRI) and magneto-encephalography (MEG), as non-invasive alternatives to the Wada test - the invasive alternative commonly used in the field. The sensitivity and specificity of the MEG was 100% and 87.5% as compared to the Wada test. Even though the results obtained with the fMRI and NIRS were not as substantial, the three tests seem to offer a valid alternative to the Wada test. Given at the good statistics of MEG and the similarity between MEG and EEG, we can expect to achieve equally satisfactory results. Our inquiry might provide scientists with more insight in language impairments, as well as with more knowledge about the process of first and second language acquisition. The issue of lateralization, in particular, is an important variable in the debate on the critical period of language acquisition.

3. Methods

Subjects

Subjects consisted of 10 undergraduate student volunteers (18-25 years old) without neurological antecedents and with normal EEG. They were non-native speaker of English, with a high fluency level.

Input

The chosen input was a passage taken from the first lines of Charles Dickens' novel *The Tale of Two Cities.* The audio fragment was cut from an audio book, read aloud by a male voice with a standard

American accent. As such, the variables that might have affected speech perception (pitch, accent) were kept as neutral as possible.

The fragment was composed of a single long sentence (118 words) divided in two parts. The first lines were a sequence of determiner phrases, separated by commas, carrying pairs of opposite semantic content (*It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness..*); after an hyphen, the structure became more complex, with several embedded clauses. The fragment is given below.

> It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness, it was the epoch of belief, it was the epoch of incredulity, it was the season of Light, it was the season of Darkness, it was the spring of hope, it was the winter of despair, we had everything before us, we had nothing before us, we were all going direct to Heaven, we were all going direct the other way - in short, the period was so far like the present period, that some of its noisiest authorities insisted on its being received, for good or for evil, in the superlative degree of comparison only.

Tasks

The tasks to be performed during the EEG recording were as follows:

T1: listening to the text fragment (43 seconds);

T2: uttering aloud the same fragment while reading it on the screen.

In T1, the subjects had to listen to the text. In order to eliminate external noises, we made use of earphones. After T1, there was a pause of 2 seconds, after which a written transcription of the text was displayed on the screen. During the entire session, the subject's brain activity was recorded with the EEG.

Recording technique

Electroencephalography (EEG) is a non-invasive technique that measures the electrical activity along the scalp produced by the firing of neurons in a particular point in time. Differently from other widely used neuroimaging techniques - such as the functional magnetic resonance imaging (fMRI) - EEG allows a high temporal resolution. EEG shows the neural activity in form of rhythmic oscillations at a variety of frequencies. The oscillation represent the synchronized activity over a network of neurons with similar spatial orientation. The raw signal triggered by this activity is transformed and divided into bands by frequency. The bands captured by our device are *delta* (up to 4 Hz), *theta* (4 to 8 Hz), *alpha* (8 to 13 Hz) and *beta* (13 to 30 Hz). These bands are the most statistically common types observed in cerebral activity; however, it should be noted that their boundaries are not strict and may be subject to changes according to the specific need of the researcher.

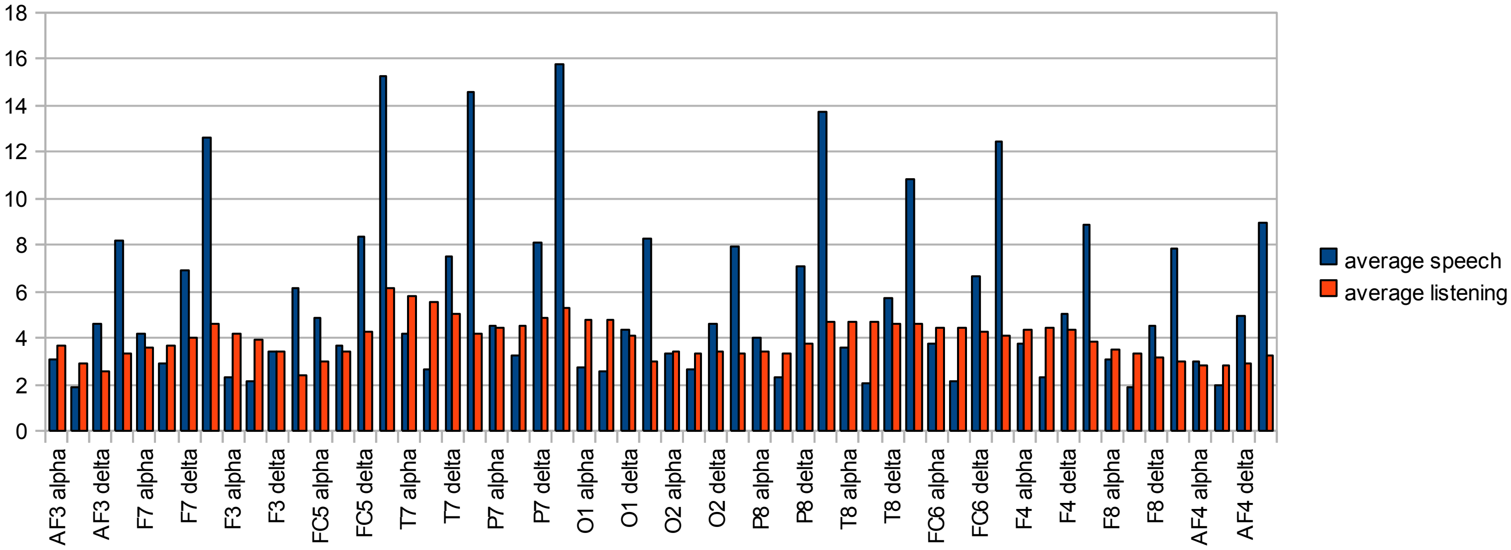
Each kind of wave is to be observed in particular cognitive state. In humans, beta waves are are related to a very alert state of mind, e. g. anxiety and concentration; alpha waves indicate relaxation; theta waves have been linked to short-term memory operations, spatial learning, reward learning, and similar cognitive control tasks; delta waves, finally, are related to the deepest phases of sleep.

The device used in our experiment was a wireless headset equipped with 16 electrodes (of which two reserved only as alternate reference location), 8 per each hemisphere. Each electrode is labelled by one or two letters and one number, where odd numbers indicate electrodes placed upon the left hemisphere and even numbers indicate electrodes placed upon the right hemisphere.

4. Experiment and results

Subjects were seated in a comfortable chair in front of the video monitor. They were requested to seat as still as possible in order to limit noises and other disturbing factors. Since none of them was acquainted with the fragment prior to the experiment, T2 has been particularly challenging. Difficulties have been encountered in uttering the second half of the passage; many of the subjects stumbled over the longest words (*incredulity*; *noisiest*). The majority of them did not pay attention to follow the syntactic flow of the passage and read it without apparent emotional involvement nor particular semantic awareness. We had to allow plenty of time for the text to be displayed on the screen, since we noticed that the reading speed of the subjects varied greatly.

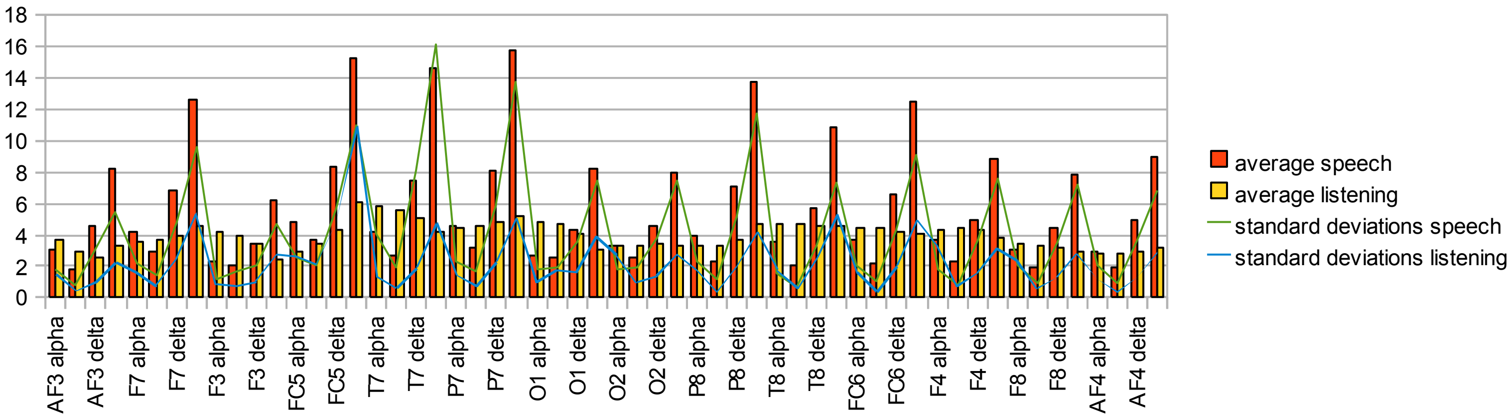
The first stage of our data analysis consisted of collecting all our data in one file and calculating the average activity of every wave for every electrode. The results are plotted in Graph 1 to compare the brain activity average of T1 (speech perception) with brain activity average of T2 (speech production).



Graph 1

The most prominent areas are those monitored by electrodes P7, T7, and FC5, placed over the left hemisphere of the brain. P7 node covers Brodmann areas 37, 22, 40, and 39 in the left occipitotemporal lobe, which corresponds to Wernicke's area. T7 node, which covers Brodmann 42 in the left middle temporal lobe, also covers Wernicke's area. Lastly, FC5 is closely related to the opercular part of left Broca's area.

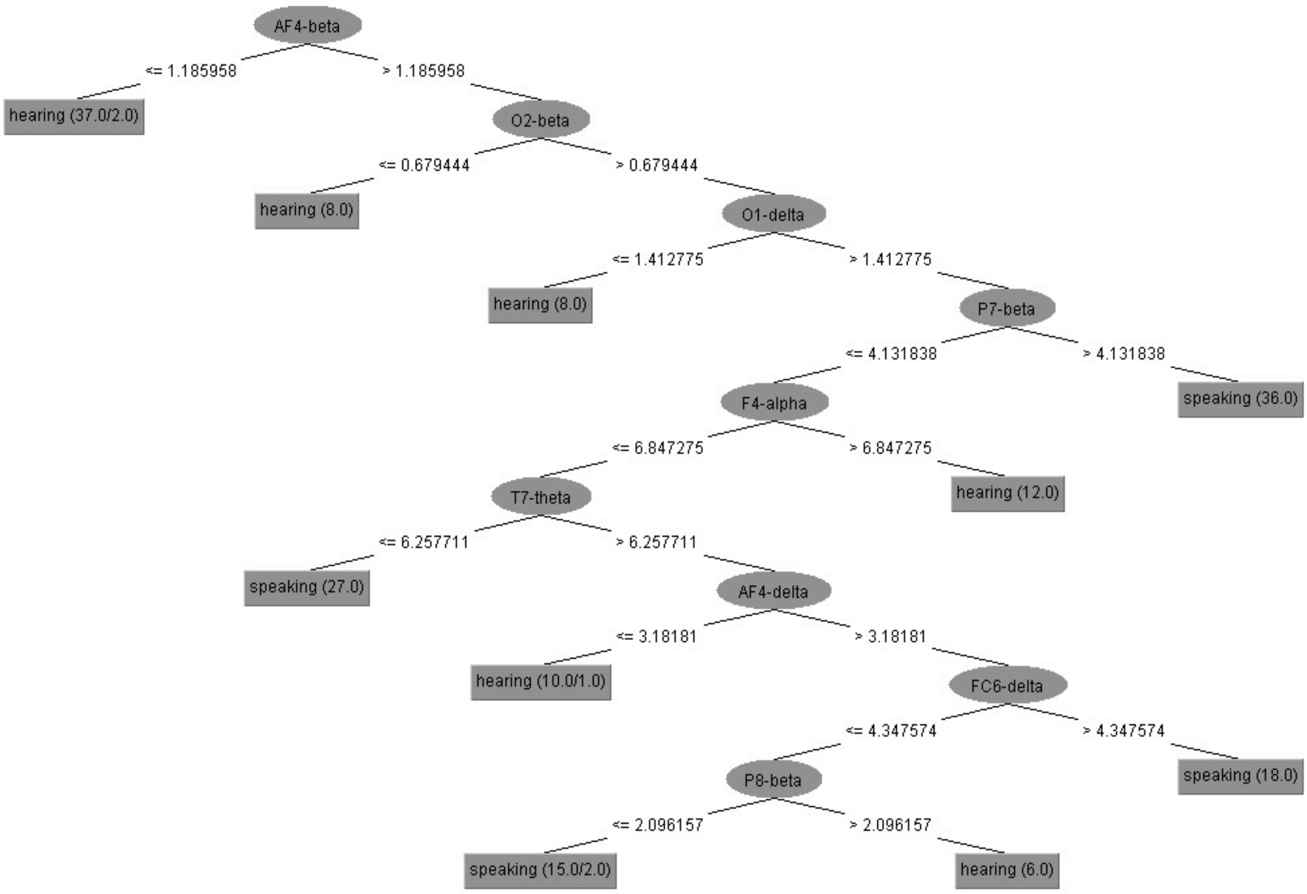
As shown in Graph 1, the biggest difference in activation between the two tasks is to be found in theta waves. Further analysis of the data showed that theta waves also have large variance in relation to speech (indicated in Graph 2 by the standard deviation curve) which remained after the removal of outliers. An outlier has been defined as laying four or more standard deviation away from the mean. We used such a method for defining outliers so as not to lose too much data – something that occurred when we attempted to use a more restricting standard.



Graph 2

After the theta waves' correlation to speech, we could find good correlation between listening and beta waves activity as the second most yielding relation. The advantage we found with the beta waves, over the theta, is the lower variance, which suggests a much better distribution and therefore more reliable information can be deduced from it.

The second part of the analysis was conducted with the Weka software, a program specialized in finding patterns in large amount of data. We observed the computer's choice of attributes and classifiers.



Graph 3

The computer's learning is based mainly on the beta waves and not on the theta waves (Graph 3). This corresponds to the last observation we had on Excel concerning the large variance in theta waves as compared to the small variance in beta waves. The most decisive area seems to be AF4, which corresponds with Brodmann area 9 in the frontal right hemisphere. In the computer's analysis, P7 and T7 indicate the activation of the left temporal lobe during speech. These two areas, corresponding with Wernicke's area, help the computer determine 63 out of 91 speech fragments correctly. FC6, the mirror of Broca's area in the right hemisphere, also shows significance.

5. Discussion and conclusion

The salient features of the electrical activity occurring during speech production and speech perception may be summarized as follows. Both the Excel and the Weka analyses show the most prominent activity in the areas covered by the nodes P7, T7, and FC5, all located in the left hemisphere. This suggests that language is mostly processed in the left hemisphere. Yet the Weka analysis also shows the relevance of the right hemisphere (AF4, the most decisive node, and FC6). These finding suggests that the right hemisphere is also involved in language processing, even though to a lesser degree than the left hemisphere. Our findings correspond with the recent literature suggesting that language is not strictly lateralized, but more prominent in the left hemisphere.

The nodes covering the left Wernicke's and Broca's areas show most significance in our data. Furthermore, the node over the right Broca's area, FC6, is also relevant in the Weka system. These data indicate that language is mostly localized in these areas; however, we have not enough significant quantitative data showing the different levels of activation of the respective areas during the different tasks. We can therefore not answer our hypothesis concerning the activation of the areas in relationship to either speaking or hearing.

The most prominent findings of the experiment, in fact, concern the brain waves. We found noteworthy differences between the types of brain waves produced during the two tasks. Our data shows that in T2, the theta waves are highly activated, while they remain more inactive during T1. The beta waves, on the other hand, showed high activation during T1 and remained less active in T2. Such difference in activation was expected; however, there seems to be no evidence in the literature linking speech regularities to spontaneous oscillatory properties of brain systems for speech perception and production. Tentatively, we can say that the large variance found in theta waves might signify different states of alertness between the subjects. Beta waves are generally linked to active concentration, possibly indicating that all the subjects' attention was put in the task at hand.

In conclusion, we suggest further research in order to find convincing data to support our hypothesis. In addition, the relation of speech with rhythmic neuronal activity seems to be an interesting yet unexplored area of inquiry; with the constant renewal and innovation of technology, however, chances of achieving a greater understanding of the most striking human mean of communication are increasing.

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