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deo II

Priredile
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SPECTRAL ANALYSIS OF EEG SIGNAL IN VERBAL INFORMATION PROCESSING TASK

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The EEG is a non-invasive method to obtain information about neural activity associated with cognitive processes. Its great temporal resolution can provide data regarding the process itself within milliseconds but EEG has poor spatial resolution. The EEG is based on the voltage difference between two (or more) electrodes and represents the summation of numerous neuron activity.

The objective of the study reported was to analyze the EEG signal in verbal information processing task using spectral analysis for frequency band and power spectrum extraction. Also we wanted to determine relation between different frequency bands (Theta – θ, Beta – β and Alpha - α) and their power spectrum in different parts of the task (perception, retention and reproduction) for different stimuli (syllables, words, non-words, sentences, picture situations and picture stories).

The sample comprised of 9 subjects, right-handed, native speakers of Serbian language with no history of hearing and speech-language disorders. All subjects were not using any medication that may influence EEG signal.

After the standard procedure of EEG electrodes placement, subjects listened to a set of auditory presented verbal stimuli. After each stimulus they had a 2 second retention period time followed by a reproduction period. They were given 5 seconds for viewing picture situations and a 15 second period for the picture story followed by a reproduction period.

Differences between EEG frequency bands and power as well as their cortical representation in verbal information processing task will be discussed.

Key Words: EEG, spectral analysis, verbal information processing

INTRODUCTION

The past two decades in particular have witnessed unparalleled progress in our ability to image human brain function noninvasively. Different imaging techniques are currently available to investigate brain function based on hemodynamic (functional magnetic resonance imaging, fMRI), metabolic (positron emission tomography, PET), or electromagnetic (electroencephalography, EEG; magnetoencephalography, MEG) measurements. In order to investigate spatiotemporal dynamics of brain activity, methods that directly assess neural activity are required. By measuring electrical activity of neuronal assemblies with millisecond temporal resolution, EEG unlike hemodynamic techniques, offer the possibility of studying brain function in real time. Over the years, developments in data collection and analyses transformed EEG into one of the prime techniques for studying the human brain. In short, there are a multitude of techniques and methods available for investigation of the cortical processing and integration of information non-invasively in the human brain. In addition, there are multiple measures that can be used to quantify coupling between cortical areas. For electrophysiological signal, two main types of mechanisms in particular have been emphasized in recent years. First, cross-frequency coupling and specifically phase-to-power interaction have been proposed to be sensible mechanisms from a physiological perspective (Jensen and Colgin, 2007).

Since EEG has excellent temporal resolution it was proved to be a valid tool for research in speech and language processing. The fundamental basis of speech and language is adequate auditory perception.

Auditory perception is a psycho-physiological process consisting of a number of interconnected phases with constant sequence. These are: recognition, reaction, discrimination and memorization. The process starts with uncovering sound in the listener's close environment. The moment the sound becomes a stimulus for the organism, an adequate or inadequate reaction occurs. If the listener's auditory capacity consists of discriminating a specific auditory stimulus from others, the reaction will be adequate followed by interpretation and comprehension of the auditory information present. The end of the process of auditory perception is dependent on the aim of listening and is marked by short-term or long-term memorizing of auditory information. In addition to understanding the relations between the acoustic signal characteristics and phonetic segments, the listener needs to engage his or her knowledge on phonological, lexical, syntactic and semantic rules of a given language.

1.1. Theories on speech perception

Theories on speech perception are usually grouped into two general types in which the listener is perceived as having different roles: an active or passive role.

The theoretical stance on the listener as an active agent in the process of comprehension of the spoken message says that when the listener hears the message, the sounds are decoded based on knowledge of how they are to be expressed in speech. The listener's knowledge of articulation is the connection between the acoustic signal and identification of linguistic units. It is based on the *motor the-*

ory of speech perception stating that internal modeling of articulation movements during speech perception enables identification of sounds.

The second theoretical stance known as *analysis through synthesis* states that the listener uses a set of rules for differentiation of the acoustic signal onto an abstract set of characteristics. The same rules are used for synthesis of the speech form in speech production. The listener compares acoustic traits of the speech signal with those produced and carries out the identification.

The second group of theories sees the listener as having a passive role in the process of speech perception which is carried out by simple recognition of distinctive traits of the wave form based on which decoding is carried out. This is why listening is a sensory process with the pattern of information in the acoustic stimulus directly causing a neural reaction. The underlying mechanism in this process of recognition is usually defined as a system based on *modeled coupling* – the listeners are coupling incoming auditory patterns with a set of abstract speech patterns already filed in the brain, or as a *trait detector* – special neural receptors reacting to specific traits of the auditory stimulus such as formants, concentrates of noise energy, explosions or other universal traits. Both these stances have positive and negative implications leading to a conclusion that a combined theory is needed to offer a satisfactory explanation of speech perception (D. Kristal, 1995).

1.2. Word perception

During listening, the process of word recognition is easier when the word is located in a sentence than when presented in isolation (Jovičić, 1999, Clark & Clark, 1975). This means that the sentence context sets limits to the number of possible words the listener can use in auditory forming of a sentence with full semantic meaning. There are several more factors underlying the speed and efficacy of auditory speech identification. These are the vocabulary capacity and word distribution value. Analysis of word confusion has shown that words with a lower frequency of appearance are more easily confused with words of similar phonetic structure but with higher frequency of appearance. However, if the vocabulary is limited, the frequency of word appearance has no effect on word comprehension (Jovičić, 1999).

The identification of speech even in difficult hearing conditions is done in a physiologically simplified manner because the speech situation is highly redundant – there is more information than necessary to decode certain information. This redundancy includes a general ability to predict the nature of speech based on previous linguistic experience, the familiarity of the speaker, the theme of linguistic input, etc. The human capacity of focusing auditory attention on discriminative signal traits is also significant – these traits are known as acoustic features (Kristal, 1995).

One phenomenon which has been a topic of very few studies is perception of atypical speech. This includes speech perception in the population with different hearing, speech and language pathology. The speech of the subjects is distorted and difficult for recognition in communication. In this situation, speech as a physical phenomenon represents a damaged acoustic stimulus. In perception of these acoustic stimuli, the phenomenon of auditory illusion occurs (Jovicic, 1999). Auditory illusion in speech perception includes perception of content different than the one within the acoustic stimulus or perception of complete linguistic content even if the acoustic stimulus is damaged (Jovičić, 1999).

Restoration of phonemes includes the ability of the perceptive mechanism to reconstruct one or more phonemes which are non-existent or distorted and unrecognizable within the acoustic stimulus. The acoustic basis of perceptive restoration of phonemes is the effect of coarticulation on the one hand and the familiarity of a linguistic concept associated with the remaining stimulus on the other. Whether the restoration will match the original stimulus depends on acoustic traits of the missing part or whether these are invariant or transitional traits remaining in the stimulus, as well as the concept the word represents or lexical capacity of the listener. However, in perception of higher linguistic levels, phoneme restoration is done based on context or information within the remaining stimulus part such as words, terms, sentence or other. This implies an existence of a hierarchical effect of linguistic levels (with higher levels having a dominant effect) on perception of speech in general.

Comprehending and producing language are brain functions that require the coordinated activity of large groups of neurons. Neural communication thus involves wavelike changes in the electrical potential along neurons and their processes. These current flows are the basis for electrophysiological recordings in the brain and at the scalp surface, because changes in electrical potential can be monitored by placing at least two electrodes somewhere on the head (or in the brain) and measuring the voltage difference between them. Using neuroimaging techniques, researchers have looked at language processing from early stages of word recognition through the processing of multisentence discourses, from the planning of a speech act to its articulation. So doing reveals that the brain's processing of language involves many different kinds of operations taking place at different times and different temporal scales and in multiple brain areas. Initially, the brain cannot know whether an incoming stimulus is linguistic or not. Thus, its first task when confronted with a written, spoken, or signed word - as with any external, perceptual stimulus—is to determine what it is, or at least to what categories it might belong. That was our starting point – determination of cortical processing of auditory presented words and non-words in order to distinguish linguistic vs. nonlinguistic information processing neural substrate.

The first task for successful language comprehension involves early sensory classification of the input. It is around the time that the brain's response to words seems to first diverge from that to non-words that shows sensitivity to a word's frequency of occurrence in a given language. In short, the brain seems to process more rapidly words that it has had more experience processing. The acoustic signal corresponding to a spoken word/nonword is subject to a variety of levels of analysis by the human perceptual system. A distinction can be drawn between peripheral auditory processes of sensory detection of the waveform in the cochlear and the initial transmissions of this information to the brain via the auditory nerve and central processes operating within the auditory system in the brain (Gathercole, 2006).

1.3. Brain Rhythms in auditory perception

Brain rhythmic activity is supposed to be the neural basis of cognitive processes including auditory perception, short-term memory, semantics etc. In our experiment, presented in this paper, we wanted to study the role of each of six basic brain rhythms – delta, theta, alpha and beta in auditory perception of words and non-words Besides localization in cortex we wanted to detect dynamical processes that emerge simultaneously in the same time in different brain rhythms during auditory perception, connecting local and distant cortical regions involved in this process.

1.3.1. Delta rhythm (1–4 Hz)

Delta oscillations reflect low-frequency activity (1–4 Hz) typically associated with sleep in healthy humans and neurological pathology. In adults, delta power has been shown to increase in proximity of brain lesions (Gilmore & Brenner, 1981) and tumors (Fernandez-Bouzas et al., 1999), during anesthesia (Reddy et al., 1992), and during sleep (Niedermeyer, 1993). Delta is also the predominant activity in infants during the first two years of life. Ontologically, slow delta and theta activity diminish with increasing age, whereas the faster alpha and beta bands increase almost linearly across the life span. Collectively, these findings suggest that delta activity is mostly an inhibitory rhythm. The role of Delta rhythm in cognition is still under the question.

1.3.2. Theta rhythm (4–8 Hz)

Theta activity refers to EEG activity within the 4–8 Hz range, prominently seen during sleep. During wakefulness, two different types of theta activity have been described in adults (Schacter, 1977). The first shows a widespread scalp distribution and has been linked to decreased alertness (drowsiness) and impaired information processing. The second, the so-called frontal midline theta activity, is characterized by a frontal midline distribution and has been associated with focused attention, mental effort, and effective stimulus processing. In light of the observation that these oscillations facilitate transmission between different limbic structures, it has been speculated that theta activity may have a gating function on the information processing and memory retrieval (Vinogradova, 1995).

1.3.3. Alpha rhythm (8–13 Hz)

The alpha rhythm refers to EEG activity within the 8–13 Hz range. In healthy adults, alpha activity typically has amplitude between 10 and 45 μV, and can be easily recorded during states of relaxed wakefulness, although large individual differences in amplitudes are not uncommon (Niedermeyer, 1993). Topographically, alpha rhythms show their greatest amplitude over posterior regions, particularly posterior occipito-temporal and parietal regions. The physiological role of alpha rhythm remains largely unknown. In recent years alpha synchronization has been described during information processing (Cooper et al., 2003; Klimesch, 1999). Further complicating the physiological interpretation of alpha, emerging evidence indicates that different alpha sub-bands may be functionally dissociated, in particular with increasing task demands (Fink et al.,2005). Specifically, in cognitive tasks, lower alpha (e.g., 8–10 Hz) desynchronization (suppression) has been associated with stimulus-unspecific and task-unspecific increases in attention demands (e.g., Klimesch, 1999). Upper alpha (e.g., 10–12 Hz) desynchronization, on the other hand, appears to be task-specific, and it has been linked to processing of sensory-semantic information, increased semantic memory performance, and stimulus-specific expectancy (Klimesch, 1999).

1.3.4. Beta rhythm (13–30 Hz)

Traditionally, lower-voltage oscillations within the 13–30 Hz frequency range have been referred to as beta. In adults, beta activity has amplitudes between 10–20 μV, presents mainly a symmetrical fronto-central distribution, and typically replaces alpha rhythm during cognitive activity. Consistent with this view, beta rhythm has been shown to increase with attention (Murthy & Fetz, 1992). Collectively, these findings suggest that beta increases generally reflect increased excitatory activity, particularly during diffuse arousal and focused attention (Steriade, 1993).

1.4. Synchronous neural oscillations and cognitive processes

The recent research supports the idea that the neural oscillations revealed by the EEG are closely related to dynamic processes of cognition. They are consistent with the idea that fundamental cognitive processes arise from the synchronous activity of neurons in the brain. Moreover, specific oscillations can be identified with particular cognitive processes: theta and gamma rhythms with memory encoding and retrieval, alpha and gamma rhythms with attention suppression and focusing. These associations, in turn, promote the effort to develop dynamical models that unify the details of the time evolution of cognitive processes with those of the underlying neural processes. Such models both provide a complementary perspective on cognition to the more traditional static models, and represent progress beyond those models in our understanding of cognition.

METHODOLOGY AND PROCEDURES

2.1. Objective

Objective of our research was to analyze the EEG signal in verbal information processing task which included auditory perception of words and non-words as well as to compare it with period without auditory stimulation, using spectral analysis for frequency band and amplitude spectrum extraction. Also we wanted to determine relation between different frequency bands (δ- Delta, θ - Theta, α1 - Low Alpha, α2 - High Alpha, β1 - Low Beta and β2 - High Beta) and their power spectrum by calculating minimum and maximum amplitude values for each band. In that way we were able to determine input and output regions and vectors of auditory information processing directions in cortex. Also we wanted to determine existence of electrophysiological functional systems in auditory presented verbal information processing task and to compare them for real words, non-words and period without auditory stimulation. We decided to use term – period without auditory stimulation instead of – resting period, or state at rest, because it is inappropriate regarding the fact that brain is never in the state at rest when electrophysiology is considered. So, visual fixation of black square on white background was "auditory stimuli free" period.

2.2. Sample

Seven undergraduate students, 4 male and 3 female, aged 21-23 years, participated in this experiment. All participants were native speakers of Serbian language with no history of hearing and speech-language disorders. All subjects were not using any medication that may influence EEG signal. They passed standard hearing screening before experiment – tonal liminar audiometry, tympanometry, impendancmetry and Otoacoustic Emission (TEOAE and DPOAE).

2.3. Materials

Two sets of stimuli were used in the experiment. The first set consisted of bisyllabic words and the second set consisted of bisyllabic non-words. Each set consisted of ten stimuli. Every stimulus in the word set was balanced by its phonological counterpart in the non-word set. also stimuli were balanced in length.

2.4. Procedures

During the experiment the patients were placed in a comfortable sitting position in a sound isolated room. The first part of the experiment consisted of the recording period without auditory stimulation for 5 min during which they had a task to visualy fixate a black square on a white background. Participant were asked to minimize their movements (eye blink, head and limbs movement) as possible in order to eliminate artifacts in row EEG trace. During the second part of the experiment participants had a duty to listen a list of bisyllabic words. The period of auditory perception lasted 1 second followed by the retention period of 10 seconds and after that was a reproduction of previously heard word. The same procedure was applied using bisyllabic non-words. In this paper we analyzed the period of auditory perception of the bisyllabic words and non-words with comparation with the period without auditory stimulation. Proffesional speaker read the stimuli one by one with the same intensity and without any variation in melody, rhythm and emotional expression.

2.5. EEG recording

EEG was acquired using the Nixon Kohden Corporation, EEG 1200K Neurofax apparatus with Electrocap (model number 16 755) International, Inc., Ag/AgCl ring electrodes filled with electro-conductive gel, providing 16 EEG channels. Electrodes were positioned according to the 10/20 system in longitudinal, bipolar montage. The reference electrode was set offline to A1 and A2 (ear lobes). Resistance was kept below 5kΩ, lower filter was set on 0.53Hz and upper filter on 35Hz in order to select frequency band of interest as well as to cut off higher frequencies that might be artifacts. Sampling rate was 256Hz. According to International 10/20 system of electrode positioning following cortical regions are covered: Fp1-Fp2 (frontopolar), F3-F4 (mid frontal), F7-F8 (inferior frontal, anterior temporal, frontal-temporal), T3-T4 (mid temporal) , T5-T6 (posterior temporal), C3-C4 (central), P3-P4 (parietal), O1-O2 (occipital), Fz (frontal midline central), Cz (vertex) and Pz (parietal midline). Odd numbers represent left hemisphere and even numbers right hemisphere.

2.6. Signal analysis procedure

Spectral analyses can provide important information about the frequency compositions of EEG oscillations. Because the EEG is a dynamic, time-varying, and often non-stationary phenomenon, approaches allowing the investigation of transient changes in the frequency domain appear particularly important. To achieve this goal, various time-frequency analyses methods have been developed, including short-time Fourier Transform (STFT), which allows to compute an FFT (Fast Fourier Transform)-based time-dependent spectrum (so-called spectrogram). In our study we have used FFT in order to separate 6 brain rhythms from the row EEG trace where all of rhythms occur simultaneously. First task in signal analysis was to choose artifact free epochs in duration of 1 second. Before computing FFT each epoch was multiplied by an appropriate windowing function (Hanning window was used) in order to avoid border problems (leakage). Then FFT was computed in order to get spectrograms of selected 1-second-epoch.

Electrophysiological model of functional systems (EFS) detection – EFS represents dynamic collaboration between region with maximum and region with minimum amplitude value for specific frequency band (Radicevic et al., 2009). We used modified version of Radicevic's methodological approach. Calculating maximum and minimum amplitude values in order to determine direction of the vector of the collaboration between different cortical regions we were able to set hypothesis of existence of the electrophysiological functional systems. Regarding the hypothesis that region with maximum amplitude value for specific frequency band is an output region in information processing (region of maximal involvement in specific process) and that region with minimum amplitude value is an input region (region that is connected with output region, collaborating together), we have created a simple cortical networks for each frequency bands (brain rhythms – δ (Delta), θ (Theta), α1 (Low Alpha), α2 (High Alpha), β1 (Low Beta) and β2 (High Beta)) that are involved in auditory presented verbal information processing.

RESULTS

3.1. Trend of maximum and minimum values of the EEG signal amplitude in each of the six studied rhythms during periods which included the absence of any auditory stimuli with visual fixation of the black square on a white background.

Table 1 - The frequency of occurrence of the maximum amplitude values in the examined brain regions for δ, θ, α1, α2, β1 and β2 rhythm during the period without auditory stimulation (N = 150 epochs of 1 second)

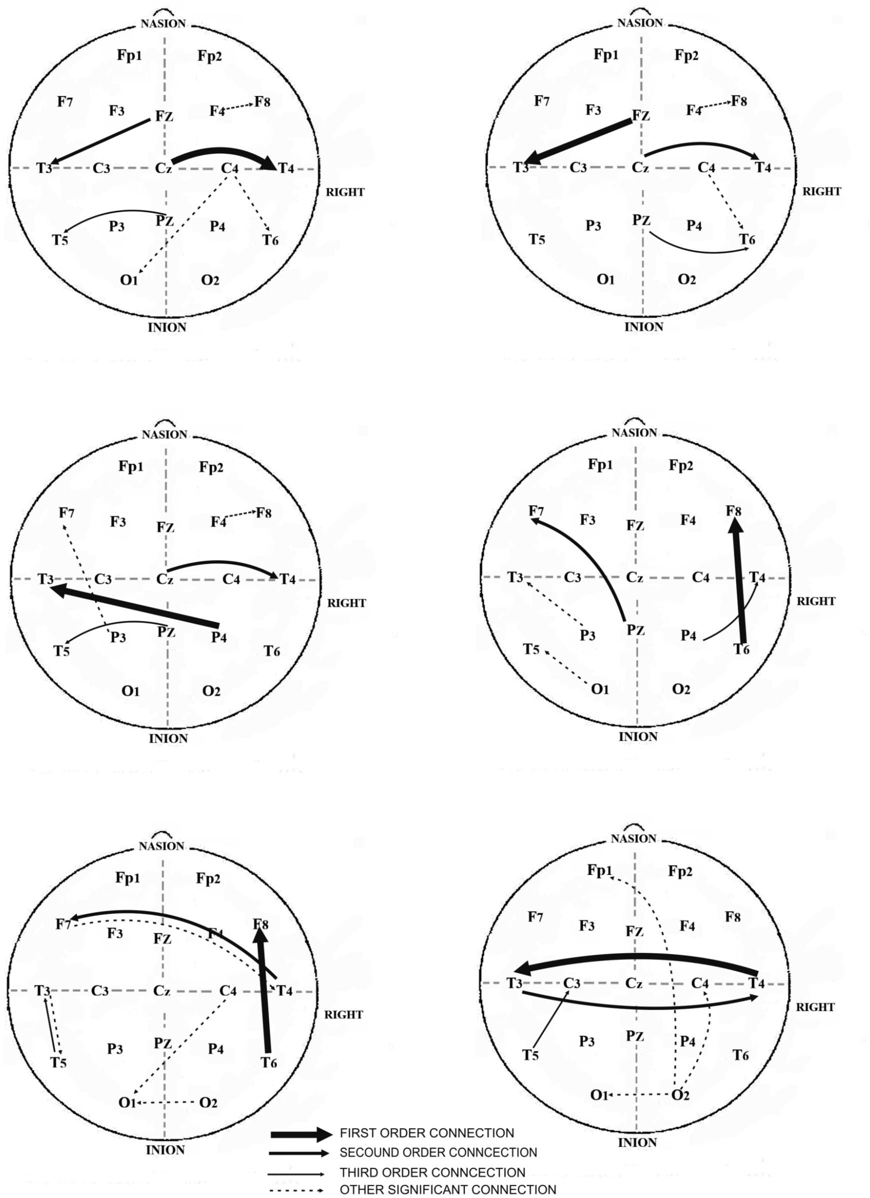
	Fp1	Fp2	F3	F4	C3	C4	P3	P4	O1	O2	F7	F8	T3	T4	T5	T6	Fz	Cz	Pz
δ	3	9	9	10	2	8	6	5	7	2	5	7	2	2	1	3	27	30	12
θ	2	5	10	12	3	3	8	8	1	5	4	2	1	0	0	1	39	31	15
α1	5	4	5	13	1	7	12	30	4	6	2	1	3	2	5	4	11	18	17
α2	2	7	2	3	2	7	14	20	12	9	4	3	0	8	7	22	3	4	21
β1	4	3	4	3	3	9	4	7	8	9	10	5	10	23	13	26	2	4	3
β2	1	1	4	6	3	2	3	3	5	11	8	6	20	31	17	15	4	8	2

Table 2 - The frequency of occurrence of the minimum amplitude values in the examined brain regions for δ, θ, α1, α2, β1 and β2 rhythm during the period without auditory stimulation (N = 150 epochs of 1 second)

	Fp1	Fp2	F3	F4	C3	C4	P3	P4	O1	O2	F7	F8	T3	T4	T5	T6	Fz	Cz	Pz
δ	2	3	2	0	1	3	1	6	12	10	11	14	23	28	18	12	2	0	2
θ	0	1	1	1	1	1	8	1	6	9	7	12	38	35	10	21	3	2	0
α1	4	4	2	1	7	2	3	1	2	9	14	16	28	25	18	10	2	1	1
α2	5	4	1	3	2	1	3	1	7	4	20	32	18	19	11	4	1	2	2
β1	9	8	1	0	5	1	1	2	10	2	22	24	21	18	11	4	3	6	2
β2	11	3	3	1	15	11	10	3	11	4	8	14	22	18	7	2	3	0	4

In the Table 1 and Table 2 we can see that in δ rhythm maximal amplitude values, during the period without auditory stimulation, are located in Cz, Fz and Pz regions respectively and minimal in T4, T3, T5; in θ rhythm maximal amplitude values are located in Fz, Cz, Pz regions respectively and minimal in T3, T4, T6; in α1 rhythm maximal amplitude values are located in P4, Cz and Pz regions respectively and minimal in T3, T4, T5; in α2 rhythm maximal amplitude values are located in T6, Pz, P4 regions respectively and minimal in F8, F7, T4; in β1 rhythm maximal amplitude values are located in T6, T4, T5 regions respectively and minimal in F8, F7, T3; in β2 rhythm maximal amplitude values are located in T4, T3, T5 regions respectively and minimal in T3, T4, C3.

Picture 1 - Electrophysiological functional systems
in period without auditory stimulation



3.2. Trend of maximum and minimum values of the EEG signal amplitude in each of the six studied rhythms during bisyllabic words perception task.

Table 3 - The frequency of occurrence of the maximum amplitude values in the examined brain regions for δ, θ, α1, α2, β1 and β2 rhythm during bisyllabic words perception task (N = 49/50 times in a period of 1 second)

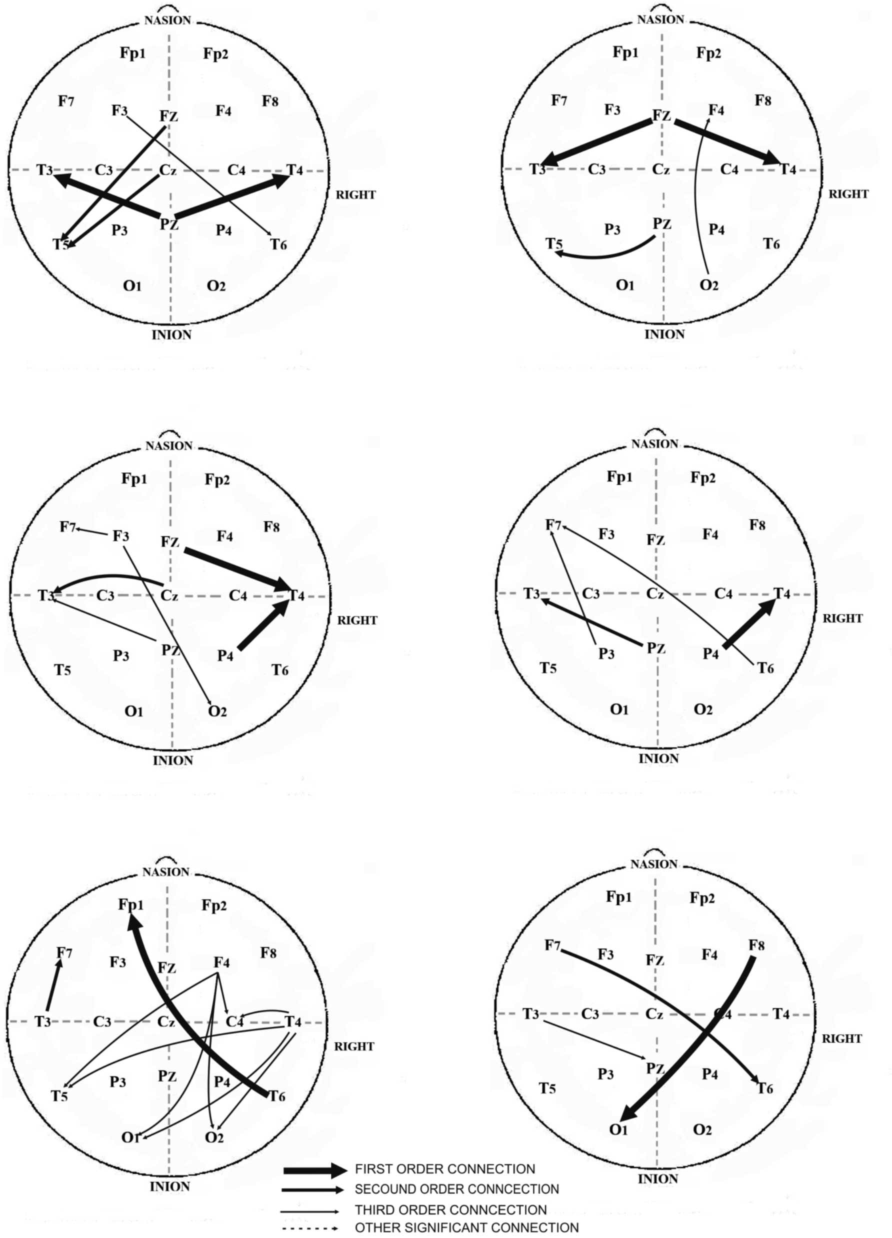
	Fp1	Fp2	F3	F4	C3	C4	P3	P4	O1	O2	F7	F8	T3	T4	T5	T6	Fz	Cz	Pz
δ	2	3	5	3	0	3	0	2	3	1	3	1	1	2	0	2	6	6	7
θ	2	1	4	6	0	3	4	2	0	0	4	0	1	1	0	0	9	4	8
α1	2	1	4	1	1	1	3	6	2	2	3	2	0	2	3	1	6	5	5
α2	0	0	1	3	1	1	5	11	4	0	0	2	3	2	3	5	0	2	6
β1	0	0	4	5	0	0	0	0	0	2	1	2	10	5	1	15	3	0	2
β2	0	1	0	0	0	0	0	0	1	0	13	15	11	8	0	1	0	0	0

Table 4 - The frequency of occurrence of the minimum amplitude values in the examined brain regions for δ, θ, α1, α2, β1 and β2 rhythm during bisyllabic words perception task (N = 49/50 times in a period of 1 second)

	Fp1	Fp2	F3	F4	C3	C4	P3	P4	O1	O2	F7	F8	T3	T4	T5	T6	Fz	Cz	Pz
δ	2	1	1	0	1	2	1	1	2	2	3	4	9	9	7	6	0	0	0
θ	1	2	0	0	0	1	1	0	1	6	4	2	11	11	9	3	0	0	0
α1	1	3	2	1	1	3	1	1	4	5	5	2	7	8	1	4	0	0	1
α2	1	0	1	1	2	3	0	0	2	0	7	4	9	11	4	3	1	0	0
β1	6	1	2	0	2	4	1	1	4	4	5	3	4	3	4	3	0	1	2
β2	0	1	1	0	2	3	6	1	10	4	0	1	3	3	0	8	0	1	6

In the Table 3 and Table 4 we can see that in δ rhythm maximal amplitude values during bisyllabic words perception task are located in Pz, Fz=Cz and F3 regions respectively and minimal in T3=T4, T5 and T6; in θ rhythm maximal amplitude values are located in Fz, Pz and F4 regions respectively and minimal in T3=T4, T5 and O2; in α1 rhythm maximal amplitude values are located in P4=Fz, Cz =Pz and F3 regions respectively and minimal in T4 T3 and O2=F7; in α2 rhythm maximal amplitude values are located in P4, Pz and P3=T6 regions respectively and minimal in T4, T3 and F7; in β1 rhythm maximal amplitude values are located in T6, T3 and F4=T4 regions respectively and minimal in Fp1, F7, C4=O1=O2=T3=T5; in β2 rhythm maximal amplitude values are located in F8, F7 and T3 regions respectively and minimal in O1, T6 and P3=Pz.

Picture 2 - Electrophysiological functional systems during auditory perception of bisyllabic words



3.3. Trend of maximum and minimum values of the EEG signal amplitude in each of the six studied rhythms during bisyllabic non-words perception task.

Table 5 - The frequency of occurrence of the maximum amplitude values in the examined brain regions for δ, θ, α1, α2, β1 and β2 rhythm during bisyllabic words perception task (N = 49/50 epoch in a period of 1 second)

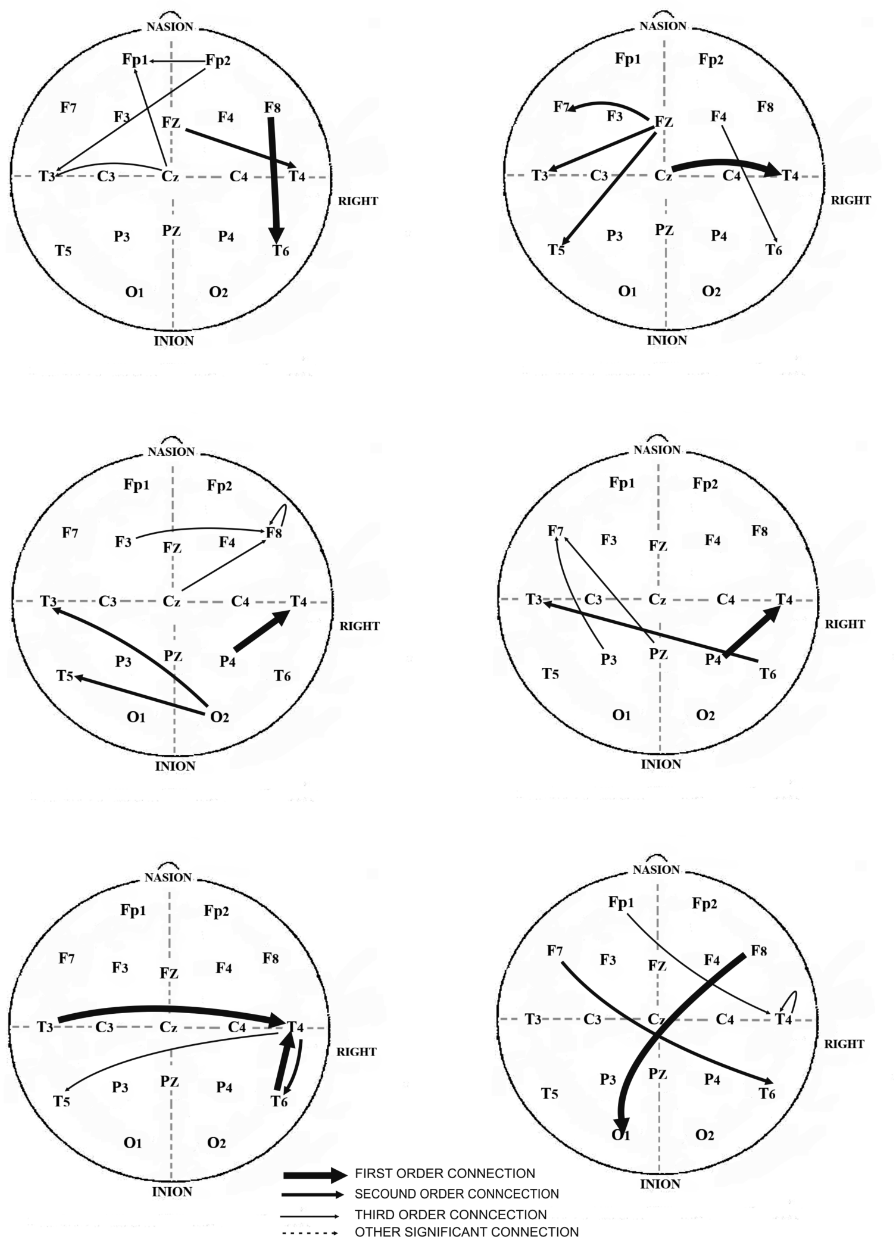
	Fp1	Fp2	F3	F4	C3	C4	P3	P4	O1	O2	F7	F8	T3	T4	T5	T6	Fz	Cz	Pz
δ	2	5	0	4	0	1	2	1	1	0	0	8	0	0	0	1	6	5	4
θ	0	0	2	5	1	1	2	3	0	1	1	0	0	0	0	0	9	11	4
α1	0	1	4	3	0	1	1	8	1	5	1	4	0	0	2	1	3	4	1
α2	1	2	1	0	1	1	4	10	0	2	0	1	0	0	1	8	3	1	4
β1	0	1	1	1	0	0	1	2	1	2	2	2	9	6	2	8	0	0	2
β2	5	1	0	0	0	0	0	0	0	0	10	17	1	6	0	0	0	0	0

Table 6 - The frequency of occurrence of the minimum amplitude values in the examined brain regions for δ, θ, α1, α2, β1 and β2 rhythm during bisyllabic non-words perception task (N = 49/50 epoch in a period of 1 second)

	Fp1	Fp2	F3	F4	C3	C4	P3	P4	O1	O2	F7	F8	T3	T4	T5	T6	Fz	Cz	Pz
δ	5	1	0	0	2	0	0	1	3	1	2	1	5	6	2	11	0	0	0
θ	0	0	0	1	0	1	0	0	1	3	5	2	5	13	5	4	0	0	0
α1	1	0	0	0	1	1	1	1	1	2	2	3	7	10	7	2	0	0	1
α2	2	1	0	0	3	1	1	1	1	1	6	3	8	12	0	0	0	0	0
β1	1	0	1	0	2	1	2	1	2	3	1	2	3	8	5	6	2	0	0
β2	1	2	1	0	2	0	3	1	8	3	2	0	3	5	0	7	0	2	0

In the Table 5 and Table 6 we can see that in δ rhythm maximal amplitude values are located in F8, Fz and Fp2=Cz regions respectively and minimal in T6, T4 and Fp1=T3; in θ rhythm maximal amplitude values are located in Cz, Fz and F4 regions respectively and minimal in T4, F7-T3=T5 and T6; in α1 rhythm maximal amplitude values are located in P4, O2 and F3=F8=Cz regions respectively and minimal in T4, T3=T5 and F8; in α2 rhythm maximal amplitude values are located in P4, T6 and P3=Pz regions respectively and minimal in T4, T3 and F7; in β1 rhythm maximal amplitude values are located in T3, T6, T4 regions respectively and minimal in F4, T6 and T5; in β2 rhythm maximal amplitude values are located in F8, F7 and T4 regions respectively and minimal in O1, T6 and T4.

Picture 3 - Electrophysiological functional systems during auditory perception of bisyllabic non-words



DISCUSSION

One aim of electrophysiological recordings of human brain activity is the identification of the underlying sources in the brain. Information is processed in circumscribed areas of the central nervous system, and spontaneous activity also originates from specific brain structures. Thus, it appears of consequence to try to explain the topography of scalp distribution patterns in terms of anatomical localization of neuronal generators. To arrive at valid interpretations of scalp recorded data is no trivial task.

Our linguistic ability is one of the many salient characteristics that distinguish humans from other species. Another is the relative size and complexity of our brains, and surely these two features are not unrelated or logically independent. In fact, we can say that the degree of flexibility and efficiency we exhibit in this cognitive domain is a consequence of the structure of language, together with the structure of the entity that represents it and mediates its processing, the human brain.

Semantic processing of linguistic material involves the activation and selection of candidate lexical representations and the integration of the semantics of the selected representation. Functional MRI (fMRI), intracranial and neuropsychological studies have implicated three main regions in these computations: the left posterior temporal cortex, the left anterior temporal cortex and the left inferior frontal cortex (Lau et al., 2008). The evidence that we have just reviewed suggests that storage of lexico-semantic information is specific to the middle part of the posterior temporal cortex. The posterior superior temporal gyrus (STG) has sometimes been associated with semantic processing, but most evidence suggests that its role is limited to early (auditory) stages of the sound-to-meaning transformation, consistent with early models such as Wernicke's.

Several studies have demonstrated that the stimulus type can significantly affect the resulting activation (Price et al. 1996; Price; 2000; Rumsey et al., 1997, Herbster et al, 1997). Greater activation for non-word processing was observed in both the posterior superior temporal gyrus as well as the inferior parietal region.

The posterior language regions did reveal a significant increase in activation for non-word processing compared with real word processing. In previous neuropsychological and neu-roimaging studies the temporal-parietal region has been implicated as being the site of the visual word form center (Chertkow and Murtha, 1997; Howard et al., 1992), which is responsible for determining orthographic regularity and triggering the retrieval of a word's meaning, grammatical features, pronunciation, etc. (Cohen et al., 2000; Hillis and Caramazza, 1995). The temporal-parietal region, however, has been shown to be active in several auditory linguistic tasks (Binder, 1997; Price et al., 1996). Recently, it has been suggested that the inferior parietal lobe contains an interface system mediating between auditory and articulatory representations (Hickok and Poeppel, 2007).

It was hypothesized that because of the semantic associations, real words may not require a phonological storage strategy. Instead, semantic codes may play a greater role causing non-words to relay more on short-term storage than real words. Therefore, pseudowords may be expected to activate the inferior parietal region to a greater degree than real words.

During period without auditory stimulation Theta rhythm is located in central region (as it was expected) – Fz, Cz and Pz (Picture 1).

In Theta rhythm we revealed difference in processing words vs. non-words. During word perception frontal midline Theta had divergent first order connection with both mid temporal regions (Fz-T3,T4). That was not observed in non-words were frontal midline region had triple divergence to F7, T3 and T5. Interesting finding is that during non-word perception left hemisphere has complex divergent connections including inferior frontal region simultaneusly with both temporal zones of the left hemisphere. It might be an implication that analytic left hemisphere had to analyse incoming stimuli (non-word) and to separate it into its basic components (phonemes) in order to process it. In contrary, real words had involvement of parietal midline region connected with the left temporal region (Pz-T5). Regarding previously mentioned statement that parietal regions are responsible for retrieval of a word's meaning our results might have an explanation. Our recent findings are questioning previously mentioned role of posterior region in non-words processing.

During period without auditory stimulation Alpha rhythm is diffuse, undirected with vector of connection from posterior to anterior regions (Picture 1) withou any divergent or convergent connections indicating collaboration of brain regions.

Only in *Alpha rhythm* (both Low Alpha and High Alpha) we found repeating connection during auditory perception of words and non-words (Picture 2 and Picture 3). That connection is P4-T4, linking parietal and mid temporal regions of the right hemisphere. Regarding the role of Alpha rhythm in global attention and task-specific attention we assumed that first reaction of the brain on incoming auditory stimuli might be detection of its meaning. In Low Alpha rhythm during real word perception connection between frontal midline region and mid temporal region in right hemisphere was observed but not durion non-word perception. Regarding the findings that Fz region is involved in memory retrieval process it might implicate that real words are „pulled out" from memory storage and sent to P-T regions for verification. Simultaneuosly there is a connection between Pz and T3 regions during real word perception and P3-F7 during non-word perception implicating that neural proces underlining non-word perception include inferior frontal region which is active during articulation movements planing. During real words perception attention might be directed to meaning while during non-words perception towards its phonological composition becouse meaning can not be used in auditory processing. Numerous studies have shown a direct influence of attention on the extent and magnitude of cortical activation (Corbetta et al., 1995; Friston and Buchel, 2000). In addition to task difficulty, there is also a possibility that participants recognized the real words before they processed the entire word. This, too, would decrease the task difficulty of the real word task.

Auditory speech recognition involves the interplay between auditory cortical areas and posterior cortical areas (retrieve the item that connects auditory form and meaning – i.e. lexical access). When a word is selected for pronunciation, its featural composition must be known in order to provide the correct commands to the articulators. The cortical areas assumed to be involved in these final steps of production are, primarily, Broca's area (for syllabification) and motor cortical areas and other areas known for motor planning (e.g. SMA, cerebellum).

During period without auditory stimulation in Beta rhythm there are multiple undirected, isolated processes with interesting recurent connection between mid temporal regions of the left and right hemisphere (in Beta 2 rhythm). Maximal amplitude values are located in lateral regions with interhemispheric connections (Picture 1).

In Beta 1 rhythm (Low Beta) we found differeces in real word vs. non-word auditory perception. During real word auditory perception we determined connections between posterior temporal region of the right hemisphere with frontopolar region of the left hemisphere as well as left mid temporal inferior frontal connections. Also complex network was obtained in posterior regions with multiple divergent and convergent connections. Underlining process is in first order connections very simple. Functional systems are divided into three basic processes – after word perception next step is to organize memorization and preparation for pronunciation with more complex semantic network that detects meaning of the stimulus. During non-word perception in Beta 1 rhythm only temporal regions were creating functional systems, both in left and right hemisfphere connecting mid temporal and posterior temporal regions with recurent connections in right hemisphere without any other regions. It might be explained by the simplicity of real words perception. They already exist in knowledge and have to be „simply" pulled out from storage while non-words have to be analysed and without cue kept in auditory regions for repeated computations (Picture 2 and Picture 3).

Beta 2 rhythm (High Beta) showed less differences during word vs. non-word auditory perception. It might be explained by the general role of higher brain rhythms in cognition. Beta 2 rhythm is generaly involved in anticipation processes. Participants in our experiment had a task to repeat heard word and basic anticipation was the same in both word and non-words. Only difference was found in a existance of single monocentric recurent conncetion in T4. Regarding existance of recurent connections in Beta 1 rhythm in T4 region (Picture 3) we conclude that right mid temporal region might be a region of interest in non-word perception task.

The role of Delta rhythm in auditory perception of words vs. non-words is questionable, becouse of the possible movement artifacts. Althou differences were obtained – divergent Pz-T3,T4 connection, simmilar to Theta rhythm, was detected during word perception while dominance of right hemisphere in non-words perception, they are hard to explain due to previously mentioned possible artifacts. Also the Delta rhytm role in cognitive processes is mainly unknown, especially in adults.

One relatively generic model that attempts to capture these recent developments and integrate the cognitive requirements of speech perception with known neuropsychological and neuroimaging findings postulates that there is a dual stream of information processing (Hickok & Poeppel, 2007). The incoming signal's spectrotemporal properties are initially analyzed in the dorsal and posterior superior temporal gyrus (STG) and superior temporal sulcus (STS). Critically, these early computations are mediated bilaterally in the superior temporal cortex

(Binder et al., 2000), although the left and right cortical areas have important computational specializations (with regard to timing properties) that contribute differentially to the recognition process. Two processing streams originate from this early spectrotemporal analysis. A ventral pathway incorporates middle temporal gyrus, inferior temporal sulcus, and perhaps the inferior temporal gyrus. The ventral stream maps from sensory/phonological representations to lexical or conceptual representations (i.e., sound to meaning). A dorsal pathway, including the Sylvian parietotemporal area (SPT) as well as the inferior frontal gyrus, anterior insula, and premotor cortex, forms the substrate for mapping from sensory/phonological representations to articulatory-motor representations. While early cortical analysis is indisputably bilateral and much of the processing in the ventral stream is more bilateral than previously assumed (Binder et al., 2000; Hickok & Poeppel, 2007), the dorsal pathway is left-lateralized.

What we do know is that language processing is a complex skill engaging the whole brain. The goal of electrophysiological investigations of language, as well as the goal of research exploring language processing with other tools, is to fashion an understanding of how the various processes involved in language comprehension and production are coordinated to yield the message-level apprehension we attain from reading or listening to speech. Linguists, psycholinguists, and neurolinguists alike strive to understand how the brain "sees" language—because, in turn, language is such an important facet of how humans "see" their world.

CONCLUSIONS

1. The existance of electrophysiological functional systems in verbal information processing task need further investigation and development of methodological designes.
2. Auditory word/nonword processing is subserved by a large-scale neural network, which includes the inferior frontal gyrus, the posterior superior temporal gyrus, the inferior parietal lobe as well as inferior frontal regions.
3. during non-word perception left hemisphere has complex divergent connections in Theta rhythm
4. During real words perception attention might be directed to meaning while during non-words perception towards its phonological composition becouse meaning can not be used as a cue in auditory processing.
5. right mid temporal region might be a region of interest in non-word perception task
6. In Beta 1 rhythm (Low Beta) we found T3-F7 (left mid temporal – left inferior frontal), connection only during real words auditory perception.
7. Is the first reaction on incomming verbal stimulus detection of its meaning.

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