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OSCILATORY BRAIN DYNAMICS DURING LEXICAL PROCESSING[2]

This paper presents an overview of research in the field of cortical processing of words and nonwords in the light of oscillatory brain dynamics and neurocognitive networks. Neurophysiological methods are aimed at better specifying the features of a word, the organization of different kinds of information associated with a word, and various influences on word processing. A fundamental issue in researching neurocognition of language comprehension is how the dynamic binding of the distributed nodes of the language network takes place. The results from the studies on brain oscillations during linguistic processing are promising. It seems that it is possible to study the dynamics of the brain language network by means of analyzing event-related changes in brain oscillations in a wide range of frequencies. Brain imaging studies have shown that a large number of brain areas are involved in processing of words and syntax. Electrophysiological signs of semantic relations between words have been investigated primarily using the lexical decision task. Reaction time and neurophysiologic measures indicate that the processing of a single word is facilitated by prior occurrence of a semantically related word. This facilitation, known as semantic priming, reflects the way in which word representations are organized in our mental lexicon. This paper reviews latest opposite

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findings in brain dynamic relations during real and non-word processing emphasizing different regions involved in this process.

Key words: *Brain dynamics, words and non-words processing, neurocognitive networks*

INTRODUCTION

One of the intriguing questions in the study of human language processing is the way linguistic phenomena are represented and processed in the brain. Today, many methods are available to study brain anatomy and, more interestingly, also brain activity simultaneously while the subject is performing cognitive, e.g., linguistic tasks. Both PET (positron emission tomography) and fMRI (functional magnetic resonance imaging) provide information about brain activity with a good spatial resolution. Thus, fMRI and PET show activation localized to specific regions, i.e., „where" activations take place in the brain. On the other hand, temporal resolution of these methods is poor (between seconds and minutes). In contrast, the EEG (electroencephalogram) and the MEG (magnetoencephalogram) provide information about brain activity with a good temporal resolution, on the level of milliseconds (Djokovic et al, 2010). The spatial resolution of the EEG and MEG is, however, relatively poor. The EEG is one of the oldest psychophysiological methods but it is still successfully being used to assess brain activity, because it is a relatively inexpensive brain imaging method with an excellent temporal resolution. Event-related potentials provide a continuous, real-time measure of neural processing that is potentially sensitive to qualitatively different kinds of information (Kutas et al. 2000). Therefore, the ERPs have been used also by language researchers for the past two decades to uncover the time at which different types of information about words is processed. Event-related potentials are small voltage shifts in brain electric activity (EEG), which can be recorded from the scalp. ERPs occur in association with motor, sensory and cognitive events and they are time locked to stimulus presentation. However, these modest electrical potentials are revealed only after averaging EEG samples over many stimulus repetitions. This summation operation removes the background activity not time-locked to the presentation of the stimulus, revealing the underlying response. ERP components are typically identified by their polarity (positive or negative), latency (occurrence after the eliciting stimulus, in ms) and amplitude (in μV). It has been suggested that ERP observations on language processing show that ERP method is a power tool for tapping the time course of language comprehension (Kutas & Schmitt 2003). However, based on the available ERP data, it seems plausible to assume that there is a significant amount of temporal overlap and interaction between various linguistic representations. Currently available data seems to be in agreement with the interactive models of word recognition: during word processing, different kinds of word-related information are activated in parallel, available after initial orthographic or phonemic analysis of a written or spoken word (Barber & Kutas 2007, Van den Brink & Hagoort 2004).

Dynamic cortical networks in cognitive processes

Cognitive function is supported by operations of cortical networks that are organized both at a local scale within areas and at a large scale extending across the cerebral hemispheres (Bressler, 1995). Second, cognitive function depends on changes in both local and large-scale cortical structure as it undergoes development over the lifespan wrought by genetically-driven processes and by experience. Third, memory is represented in cortical networks and is accessed in cognitive function by cortical network operations (Fuster, 2006). Fourth, cortical network operations are controlled and modulated by subcortical structures (Bressler, 1995; Mesulam, 1998, 1990; Houk, 2005). Fifth, neurocognitive network operations are labile, and neuronal populations across the cortex are linked in different operational configurations at different times depending on the task at hand. Finally, the local expression of knowledge in one cortical area is dependent on a neural context (Bressler and McIntosh, 2007) created by its reentrant interactions with other areas (Bressler, 2004). Neurocognitive networks are large-scale systems of distributed and interconnected neuronal populations in the central nervous system organized to perform cognitive functions. Networks of the cerebral cortex are embedded in more widely distributed networks in the brain that provide reciprocal connections between many cortical areas and subcortical structures. The modern understanding of neurocognitive networks gradually emerged over the past two centuries as a resolution of the longstanding antagonism between two opposing views in neuropsychology. The first, localizationism, holds that complex cognitive functions are localized to specific brain regions, whereas the second, globalism, posits that they are global functions of the brain. Localizationist theory can be traced as far back as Gall's doctrine of phrenology, which was based on faculty psychology, whereas the origins of globalism were evidenced by the work of Flourens (Young, 1990). The reconciliation of these views began with Wernicke's (1874/1977) idea that complex functions of cognition are properties of distributed systems of linked brain regions, and are composed of elementary functions expressed by the individual regions. Building on this theme, Luria (1962/1977) offered a redefinition of functional localization in terms of networks „of complex dynamic structures" in the nervous system that are „united in a common task". This line of thinking has led to the modern conception of cognitive function resulting from integrated processes in distributed networks, the nodes of which are interconnected brain areas (Goldman-Rakic, 1988). From this perspective, cognition is viewed as a higher-order function that emerges from the dynamic interactions of distributed network nodes. Fuster (2003) has observed that a paradigm shift to this network view of cognition is currently underway in cognitive neuroscience. The interplay of interconnected executive cortical areas that control cognitive function is critical to an understanding of neurocognitive network function. Multiple high-level control areas are thought to interact while controlling the spatial and temporal dynamics of such functions as selective attention, working memory, and language processing (Mesulam, 1990; Posner and Rothbart, 2007; Just and Varma, 2007). The same executive control networks may perform a similar role in each of these seemingly different cognitive functions.

Neurocognitive networks are composed of neuronal populations that operate and interact according to dynamic principles (Nunez, 2000). The prevalence of bidirectional connectivity between network populations suggests that a basic mechanism subserving neurocognitive network function is reentry at the level of cortical areas, whereby populations distributed throughout the cerebral cortex cooperatively process information using recurrent transmissions (Tononi et al., 1992; Friston, 2005). 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.

In our previous research (Djokovic et al., 2010) we hypothesized the existence of the *electrophysiological functional systems (EFS)* that represents dynamic collaboration between region with maximum and region with minimum amplitude value for specific frequency band during auditory perception of words vs. non-words.

Cortical processing of words and non-words: What is the word?

From the brain's perspective, language is mapping between physical inputs/outputs, in the form of written, spoken, or signed signals, and experiences, memories, and knowledge stored in long-term memory. One of the critical units for such mapping is the word. Neurophysiological methods have been aimed at better specifying the features of a word, the organization of different kinds of information associated with a word, and the various influences on word processing. One proposal is that information about words is represented in a mental „lexicon" containing both lower-level phonological and orthographic information, as well as higher-level information about the meaning of a word and its various syntactic properties (when applicable), such as grammatical gender and subcategorization On the standard model, recognizing a word activates this information in the lexicon, in a process known as „lexical access." This information, in turn, is used to combine the meanings of words into phrases and the meanings of phrases into sentences and discourses.

Initially, a linguistic stimulus is just another sensory signal – a pattern of light hitting the retina or a constellation of sound pressure waves reaching the cochlea. It is not surprising, therefore, that the earliest brain responses to language are indistinguishable from those to other types of visual and auditory inputs. Eventually, however, the brain begins to categorize (and thus respond differentially to) the input, for example, as a visual string rather than a single object, as a familiar event rather than a novel one, as belonging to the class of stimuli that may be associated with meaning. When and how these classifications unfold are critical questions that have been partially answered.

Lexical items are divided into different word classes, such as nouns and verbs, because they play different semantic and syntactic roles in language and, in behavioral tasks, are responded to differentially by language users. For example, whereas nouns are pointers to objects (people, places and things), verbs generally refer to actions and states. Verbs have been described as more `relational' in their semantics than nouns (Gentner, 1981; Langacker, 1987). In any given language, nouns and verbs typically receive different types of inflectional (grammatical) markings and/or appear in different canonical places in the sentence structure. Perhaps because of these semantic and syntactic differences, nouns are acquired earlier during language development (Nelson, 1973) and are remembered more easily than verbs (Thios, 1975; Reynolds and Flagg, 1976); nouns are also less likely than verbs to be altered during within-language paraphrasing or across-language translation (Gentner, 1981).

Semantic relations between words

Reaction time and neurophysiologic measures indicate that the processing of a single word is facilitated by the prior occurrence of a semantically related word. This facilitation is known as semantic priming and it reflects how word representations are organized in our mental lexicon. Electrophysiological signs of semantic relations between words have been investigated primarily using the lexical decision task (Bentin, McCarthy, & Wood, 1985) and the category membership verification task (Boddy & Weinberg, 1981). In both tasks, ERPs to semantically primed words are more positive between 200 and 500 ms than are those to unprimed words, with the difference presumed to be a member of the N400 family. While the N400 effects in different modalities as well as cross-modally (Holcomb & Anderson, 1993) are similar in comprising a monophasic negative wave between 200 and 600 ms, they differ in amplitude, onset latency, and/or scalp distribution (Holcomb & Neville, 1990). Distributional differences and the reliability with which N400 amplitude is modulated by semantic relations has made it a useful metric for testing various hypotheses about language processing.

A central characteristic of language comprehension is that very different sources of information, including information about form, syntax, and meaning of words and sentences, have to be accessed and combined very rapidly. Brain imaging studies have shown that a large number of brain areas are involved in processing each of these relevant types of information. Since different bits of information processed in different parts of the brain must be integrated to obtain a unified concept of the language input at a given moment, the different brain areas involved have to communicate with each other. A fundamental issue in research on the neurocognition of language comprehension is therefore how the dynamic binding of the distributed nodes of the language network takes place, transforming form onto meaning. A good candidate mechanism for such dynamic network formation is that of synchronization and desynchronization of oscillatory neuronal activity.

The spectral composition of EEG data can be obtained with a comparably high temporal resolution using short-time spectral analyses. Depending on the required frequency band and its bandwidth, the time resolution of this technique is better than hundreds of milliseconds allowing for a successful evaluation of dynamical patterns of brain activity. Moreover, this approach warrants that the brain signals of time- but not phase-looked processes are preserved after averaging across repeated events, thus, revealing aspects of brain activity that are not visible with time-domain analysis. Due to the low spatial resolution of EEG, it is difficult to compute source locations of various oscillatory activities.

The question of whether oscillations in neuronal networks, as reflected in brain waves, are merely epiphenomena or reflect general functions is still under debate. It has been suggested that higher-frequency oscillations - 20 Hz may mediate the formation of assemblies of neurons that represent a given stimulus pattern. The activity of such an assembly of neurons or cell assembly is characterized by the coherent firing of large groups of neurons. If these coherently activated neurons represent some part of a cortical cell assembly, then cell assemblies can be assumed to be the units by which elementary cortical functions are realized. Thus, one way of exploring these distinct cognitive processes in the human brain could be to measure coherent oscillations with non-invasive techniques, such as EEG or MEG.

Eulitz et al. (1997) showed in an experimental situation where simple lexical processing took place, that normalized spectral power was predominantly enhanced over temporo-occipital brain regions of the language-dominant left hemisphere. In contrast, during the perception of non-verbal stimuli, the enhancement of the normalized spectral power was largest over centro-parietal areas of the right hemisphere. This result might be taken as evidence for the activation of those cortical cell assemblies responsible for language processing located for the most part in the left hemisphere. On the other hand, it might be taken as evidence for the activation of other cortical cell assemblies situated for the most part in the right hemisphere, thus, accounting for the processing of non-verbal information. These conclusions are somehow different from ours (Djoković et all. 2010; Stokić et al., 2010) where we showed opposite situation emphasizing that 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. Aslo we found in Low Alpha rhythm during real word perception connection between frontal midline region and mid temporal region in right hemisphere but not during non-word perception. During real words perception attention might be directed to meaning while during non-words perception attention might be directed towards its phonological composition becouse meaning can not be used in auditory processing.

The results from the studies on brain oscillations during linguistic processing are promising. It seems that it is possible to study the dynamics of the brain's language network by means of analyzing event-related changes in brain oscillations in a wide range of frequencies. The ERPs and brain oscillations are two separate, but not necessarily independent properties of the brain. They are complementary to each other and offer a more comprehensive view of the dynamics of language processing in association with behavioral measures.

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OSCILATORNA MOŽDANA DINAMIKA TOKOM PROCESIRANJA REČI

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Rezime

Rad predstavlja pregled istraživanja u oblasti kortikalnog procesiranja reči i nereči sa aspekta oscilatorne moždane aktivnosti i neurokognitivnih mreža. Neurofiziološke metode se korsite u cilju egzaktnijeg određivanja karakteristika reči, organizovanja različitih vrsta informacija u vezi sa rečju i različitih uticaja na njihovo procesiranje. Osnovno pitanje u neurokognitivnim istraživanjima procesiranja jezičke informacije je kako se ostvaruje dinamičko povezivanje centara obrade. Rezultati istraživanja oscilatorne moždane aktivnosti tokom obrade jezičke informacije su obećavajući. Moguće je istraživati dinamiku moždane neuralne mreže zadužene za obradu jezičke informacije analiziranjem evociranih potencijala kao i analizom frekventnih opsega oscilatorne moždane aktivnosti. Imidžing studije mozga pokazale su da je veliki broj moždanih regija uključen u procesiranje reči i sintakse. Elektrofiziološki korelati semantičkih relacija uglavnom su ispitivani primenom zadatka leksičkog odlučivanja. Neurofiziološke mere su pokazale da je procesiranje reči olakšano prethodnom prezentacijom reči sa sličnim značenjem. Ovaj fenomen poznat kao semantički prajming oslikava način an koji su reči organizovane u mentalnom leksikonu. U ovom radu dat je kratak pregled oprečnih stavova o moždanoj dinamici tokom procesiranja reči i nereči ističući različite moždane regije uključene u ovaj process.

Ključne reči: moždana dinamika, procesiranje reči i nereči, neurokognitivne mreže

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