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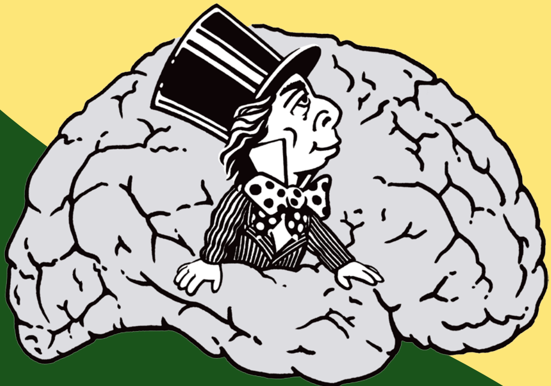

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LANGUAGE LOCALIZATION BY MEG BETA-POWER DYNAMICS DURING A SENTENCE COMPLETION TASK

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Abstract. The choice of method, task and baseline for noninvasive language mapping remains an area of active research. While the sentence completion task is recommended for fMRI studies, the indirect nature of the signal is a limitation of that method. This study presents a sentence completion paradigm for a group-level language localization based on beta-power (15–29 Hz) modulations. MEG-recordings of 21 neurologically healthy native Russian-speakers were collected during sentence completion and were used to test whether the task would elicit beta desynchronization in the conventional regions of interest related to language. To control for the linguistic input, active (syllable repetition) and passive (no task) baselines were implemented. The paradigm successfully activated both anterior and posterior language areas as a function of time, with more distributed and pronounced desynchronization appearing during the processing of the last word prior to the verbal response. However, the results remained significant only for comparison with the passive but not the active baseline condition. Nevertheless, the overall ability of the method to correctly localize language regions in the brain at the group-level can serve as a starting point for further clinical research and application of the method in individual preoperative mapping.

Keywords: beta desynchronization, MEG, language localization, sentence completion task, group-level analysis, time-frequency analysis

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Introduction

Individual mapping of the patient's brain is performed during surgical intervention to maximize the removal of pathological tissues and minimize damage to the specialized functional areas, including those related to language processing.

The most important parameter to consider for effective language mapping is the choice of the task that would fully engage the language network. To obtain sufficient information about language neural networks, it is necessary to use tasks that simultaneously require both language comprehension and production. One example of such task might be a sentence-completion task (SC) in which subjects silently read a sentence with the last word missing and are asked to complete it aloud with an appropriate word in a correct grammatical form. Empirical evidence shows that the SC task might be an effective and reliable method for language localization (Elin et al., 2022).

Most of the research on language mapping to date has been done by fMRI. However, indirect nature of the signal being recorded and low temporal resolution are the main limitations of the method. Registering direct activity of the brain by magnetoencephalography (MEG) could be a more informative method in terms of the spectral and dynamic characteristics of neuronal activity, as this method, in addition to high spatial resolution, provides temporal resolution in order of milliseconds, as opposed to seconds in fMRI. Synchronous activity of neuronal populations, or “brain oscillations”, are thought to reflect cognitive processes, and beta-frequency oscillations are often associated with linguistic processing (e.g., Piai et al., 2015; Roos, Piai, 2020).

Based on fMRI research data, we hypothesized that the SC task would activate both the anterior and posterior regions of the language network. To isolate the activity associated with language processing, we applied two control conditions: rest and syllable-repetition activity. We expect that SC will cause beta desynchronization in the conventional language-related brain areas. Presumably, this effect would intensify and spread across the cortex as the sentence unfolds. Moreover, the contrast of the proposed paradigm with syllable repetition was expected to produce more localized effects than a comparison with resting-state activity in the passive baseline.

Method

The SC paradigm consisted of 60 trials (each consisting of three words). The stimuli were taken from the study by Elin et al. (2022). Sixty syllables were created as an active baseline. Each syllable began with a consonant followed by as many vowels as the number of phonemes present in the real word corresponding to this syllable. For example, the sentence “Серый кот ловит” (“The gray cat catches”) would correspond to the syllables “Таааа таaa таaa” (“Taaaa taaa taaa”). Trials with sentences and syllables appeared in random order. The stimuli were presented on the screen word by word for 500 ms with 300 ms pauses. After the last (third) word, the screen remained blank for 3000 ms which was followed by omission points for 2000 ms indicating the time for verbal response to complete a previously read sequence to a meaningful sentence. For the syllable baseline, the task was to repeat the syllable presented earlier. We have identified 52 regions of interest (ROIs, 26 in each hemisphere) and five time intervals of interest (TOI) corresponding to each word processing during the SC task, passive baseline, and the third syllable processing during the active baseline. TOIs did not include the verbal response itself due to signal distortion caused by muscle artifacts.

Limitations. In this work, we limited our study to the beta rhythm, but oscillations of other frequency ranges could also reflect language-related processes.

Table 1. The Summary of 52 Mixed-Effects Models After Correction for Multiple Comparisons (Only Significant Fixed Effects are Shown)

Baseline	TOI	Significant ROI	Estimate	*t*(*df*)	*p*-value (Bonf.-corrected)
Passive	Word 2	Left IFG (pars opercularis)	−6.46	−3.99 (60)	1.84×10^{-4}
		Left postcentral gyrus	−9.03	-5.42 (60)	1.10×10^{-6}
		Left precentral gyrus	−8.41	−5.28 (60)	1.85×10^{-6}
		Left STG	−6.95	−5.80 (60)	2.63×10^{-7}
		Left SMG	−8.60	−4.61 (60)	2.12×10^{-5}
	Word 3	Right angular gyrus*	13.31	6.60 (60)	1.19×10^{-8}
		Left MFG	−6.02	−3.98 (60)	1.88×10^{-4}
		Right MTG*	5.95	4.33 (60)	5.68×10^{-5}
		Left IFG (pars opercularis)	−9.93	−6.13 (60)	7.36×10^{-8}
		Left IFG (pars triangularis)	−7.21	−5.31 (60)	1.66×10^{-6}
		Left postcentral gyrus	−9.14	−5.49 (60)	8.57×10^{-7}
		Left precentral gyrus	−10.04	−6.30 (60)	3.77×10^{-8}
		Left STG	−7.16	−5.99 (60)	1.39×10^{-7}
		Left SMG	−8.98	−4.82 (60)	1.02×10^{-6}

Note. Word 2: 800 – 1600 ms, word 3: 1600 – 5100 ms.
* ROIs of significant beta desynchronization relative to the baseline condition.

Additionally, the study was conducted on a group of healthy subjects in predetermined ROIs, though the localization of speech may vary widely and extend beyond the areas analyzed.

Results

No significant beta desynchronization was registered during the first word processing (0 – 800 ms) relative to the passive baseline. At the same time, the second (800 – 1600 ms) and the third (1600 – 5100 ms) word processing elicited desynchronization in some of the conventional language-related areas, such as pars opercularis of the inferior frontal gyrus (IFG), pre- and postcentral gyri, superior temporal gyrus (STG), and supramarginal gyrus (SMG) (see Table 1 for the details). Importantly, the mentioned effect was restricted to the left hemisphere irrespective of participants' handedness, which is consistent with the idea of left lateralization of the language network. During the processing of the third word, in addition to already mentioned left ROIs, the middle frontal gyrus (MFG) and pars triangularis of the IFG were also involved. However, activity in the angular gyrus and the middle temporal gyrus (MTG) of the right hemisphere was also significant in this TOI. While the left ROIs demonstrated beta-power decrease, the right ROIs showed significant increase in beta power during the processing of the third word.

The obtained results indicate that not only did the distribution of the beta desynchronization became wider, involving four additional brain areas during the third time interval as compared to the second, but the decrease also became more prominent with time. For the regions significantly activated during both intervals, beta-power decrease relative to the passive baseline condition was much stronger during the third word processing as compared to the second word processing. For instance, beta power in the left IFG (pars opercularis) was almost 6.5 points lower during the second interval than in the passive baseline. However, this parameter increased by 50 % reaching −9.93 points for the third TOI.

Discussion and Conclusions

The results of the study mostly support the hypotheses. Processing of the second and third word during the SC task have led to a pronounced beta-power decrease in most of the left-hemispheric language areas. Thus, the results mainly support data of the previous fMRI research where the SC paradigm was associated with activation in the frontal and temporo-parietal regions (Elin et al., 2022). The results might indicate that the SC paradigm sufficiently activates language-related areas in the brain allowing to detect temporal modulation of beta power on a group level. Additionally, our results further support the hypothesis about the intertrial beta modulation: the number of involved ROIs increased from the first to the third word analysis. Noticeably, the first word processing did not lead to any significant activation, but the second word processing was associated with more posterior brain areas, such as the SMG which is considered to be an important node in phonological processing (Deschamps et al., 2014) and verbal working memory, including information update (Clark et al., 2000). Importantly, the SMG was found to be involved not only in word processing, but also in syllable processing (Dehaene-Lambertz et al., 2005). This evidence could potentially account for the absence of significant difference between sentence and syllable processing in the current study.

Both pre- and postcentral gyri, associated with motor planning and execution and somatosensory processing, were also involved in later intervals of sentence processing. One of the possible explanations could be derived from the study by Gale et al. (2021). The authors have found a synergetic modulation in both sensorimotor regions in motor preparation suggesting that apart from the primary motor area, motor planning might engage somatosensory cortex to predict sensory feedback from the upcoming movement. The same effect could be detected in our study, since the task was not only to comprehend a sentence but to complete it out loud.

Pars opercularis and pars triangularis of the left IFG constitute another set of regions vital for language processing that were engaged in the experimental task. Both areas have been shown to be related to syntactic processing and causally involved in speech production (Lazar, Mohr, 2011). Accordingly, their joint activation was evident during the latest stage of the sentence processing prior to verbal response.

Furthermore, the SC task also elicited desynchronization in the STG which in conjunction with the IFG constitute nodes of the arcuate fasciculus, a white-matter bundle essential for speech production and comprehension. Specifically, arcuate fasciculus is involved in the comprehension of words and sentences and spontaneous speech generation (Ivanova et al., 2016). As one of the features of the experimental paradigm is the engagement of the spontaneous speech aspect, the revealed pattern of activation speaks in favour of the paradigm validity.

However, unexpectedly, the mentioned effects were obtained relative to the passive but not against the active (syllable repetition) baseline. Presumably, it could be related to the difference in tasks demands in these conditions. Another unexpected effect was related to significant beta-power increase in the right MTG and angular gyrus. However, newly developed idea linking beta synchronization to syntactic unification (Bastiaansen, Hagoort, 2006) are in line with these data.

Nevertheless, overall results of the current research provide evidence for the SC task as a possible language localization paradigm. The task progressively involved the crucial regions of the language network as the sentence unfolded. Interestingly, it was the passive baseline condition that elicited the significant effects, while the comparison with the syllable repetition task did not provide any significant data. Testing reproducibility of the group-level results on the individual level and applicability of the paradigm for individual language mapping are objectives of the follow-up studies. Additionally, beta synchronization in the right temporal and parietal areas should be studied in more detail in the future.

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ЛОКАЛИЗАЦИЯ РЕЧИ С ПОМОЩЬЮ МЭГ ПО ДИНАМИКЕ МОЩНОСТИ БЕТА-РИТМА ВО ВРЕМЯ ВЫПОЛНЕНИЯ ЗАДАЧИ НА ЗАВЕРШЕНИЕ ПРЕДЛОЖЕНИЙ

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Аннотация. Выбор метода, задачи и контрольного условия для неинвазивного картирования речи остается областью активных исследований. Задача на завершение предложений является рекомендуемым вариантом для фМРТ-исследований, однако косвенный характер регистрируемого сигнала является ограничением метода. В данном исследовании представлена парадигма на завершение предложений для локализации речи на групповом уровне, основанная на изменении мощности бета-ритма (15 – 29 Гц). Данные магнитной энцефалографии 21 неврологически здорового носителя русского языка во время завершения предложений были использованы для проверки того, вызовет ли выполнение этого задания бета-десинхронизацию в конвенциональных речевых зонах интереса. В качестве контрольных были использованы активное (повторение слогов) и пассивное (без задания) условия. Было показано, что парадигма успешно активировала как передние, так и задние речевые области. При этом более распределенная и выраженная десинхронизация появлялась во время обработки последнего слова перед вербальным ответом. Однако эти результаты проявились только в сравнении с пассивным контрольным условием. Тем не менее, общая способность метода правильно локализовать речевые области мозга на групповом уровне может послужить отправной точкой для дальнейших клинических исследований и применения метода в индивидуальном предоперационном картировании.

Ключевые слова: бета-десинхронизация, МЭГ, локализация речи, задача на завершение предложений, групповой анализ, частотно-временной анализ

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