Hemodynamic response during a short-term memory task

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***Abstract*—This study examined hemodynamic response changes during a short-term memory task. Significant differences were identified in the hemodynamic response to high-complexity tasks within the frontal and parietal cortex. Increased oxyhemoglobin levels during later experiment stages suggest adaptation to high-complexity tasks amidst growing fatigue.**

***Index Terms*—Brain adaptation, fNIRS, Sternberg paradigm, short-term memory**

I. Introduction

Understanding the workings of the brain is a pivotal factor in expanding our knowledge of human nature. Investigating brain function through the analysis of hemodynamic reactions is a valuable method within neuroscience [1] and nurotechnology [2]. Hemodynamic reactions reflect changes in blood flow and oxygen delivery in active brain regions [3]. Analyzing these reactions allows us to observe how different areas of the brain respond to various stimuli and tasks [4]. This is crucial not only for a deeper understanding of neuronal activity but also for the development of brain training methods and the optimization of cognitive processes, which hold practical significance in everyday life and professional activities [5].

It is worth noting that the study of the hemodynamic response can be hindered when the time interval between stimuli is too small, as this can lead to an overlap of the brain's responses to these stimuli. For this reason, many studies make the distance between stimuli quite large [6]–[9].

In this study, we address these issues by using a Cluster-based permutation test. This method overcomes the limitations associated with overlapping hemodynamic responses. In this way, we shed light not only on the cognitive processes occurring during short-term memory tasks, but also on the potential of innovative methods to decipher complex brain responses to cognitive tasks.

II. Methods

The experimental task used is similar to the study in reference [10]. The task involves short-term memory and based on the Sternberg paradigm. The task begins with a black screen (1.5-2.5 seconds) displaying a white cross to attract attention. Then, 7 characters (2-7 letters and '*') are presented (1.5-2.5 seconds), and the participant memorizes them. A pause follows (3-7 seconds), after which a letter appears. The participant decides if it was in the set, within 4 seconds before the next task.

The main experiment is divided into 4 blocks. Each block consists of 72 trials: 12 for each letter quantity (2-7). 6 of them have the target letter, and 6 do not. The order of tasks is randomized. Fatigue is assessed before and after the blocks.

Hemodynamic responses were recorded using a NIRScout device from NIRx (Germany). This system operated at 7.8125 Hz and had 8 sources and 8 detectors placed on the participant's scalp over the frontal and temporal cortex. Each source-detector pair, located about 3 cm apart, formed an fNIRS channel. A total of 16 fNIRS channels were employed.

Data collection and preliminary processing utilized the NIRScout software. To address physiological noise and artifacts, like Mayer waves (around 0.1 Hz), respiration (around 0.25 Hz), and heartbeat (around 1 Hz), a bandpass filter of 0.01-0.1 Hz was applied using the NIRScout software. After filtering raw fNIRS data, changes in total hemoglobin concentration were computed using a modified Beer-Lambert law.

All tasks were categorized into high and low complexity based on the quantity of letters required to be memorized. Assignments necessitating the memorization of 5 or more letters were classified as high complexity, while those involving fewer letters were categorized as low complexity.

To analyze statistically significant differences, the method of cluster analysis with permutation testing was employed [11].

III. Results

This study focused on analyzing changes in the hemodynamic response during the course of the experiment. We identified statistically significant differences in the hemodynamic response to high-complexity tasks in the frontal and parietal areas throughout the experiment (see Figure 1). The figure

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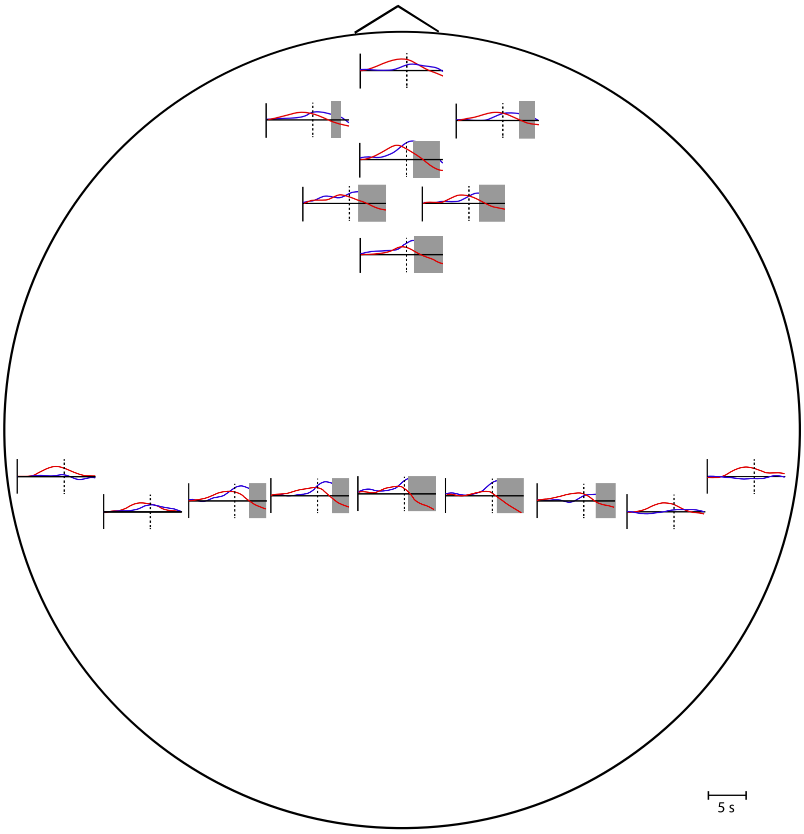

Fig. 1. Comparison of hemodynamic response (oxyhemoglobin) for high complexity at the Beginning (red curve) and at the end (blue curve) of the experimental task. Here, the start of the temporal measurement corresponds to the beginning of the trial, and the dashed line corresponds to the start of the next task.

vividly demonstrates that these differences manifest in the time interval corresponding to the onset of the next task.

Of particular interest, in the fourth block of the experiment, we observed a higher level of oxyhemoglobin in both the frontal and parietal cortex compared to the level in the first block. This may indicate the involvement of additional resources and specific adaptation of brain regions when performing high-complexity tasks during the experiment in response to increasing fatigue.

IV. Conclusions

In summary, this study investigated changes in hemodynamic responses during a task involving short-term memory. Significant differences were found in the hemodynamic response to high-complexity tasks in the frontal and parietal cortex areas. it's been hypothesized that increased oxyhemoglobin levels in these areas during the later stages of the experiment suggest additional resource engagement and specific adaptation to high-complexity tasks in response to mounting fatigue. This work enhances our understanding of cognitive responses to task demands and neural adaptation. Also it should be noted that the use of cluster analysis with shuffling is a promising method for analyzing hemodynamic responses.

References

[1] D. Attwell and C. Iadecola, "The neural basis of functional brain imaging signals," *Trends in neurosciences*, vol. 25, no. 12, pp. 621–625, 2002.

[2] A. E. Hramov, V. A. Maksimenko, and A. N. Pisarchik, "Physical principles of brain–computer interfaces and their applications for rehabilitation, robotics and control of human brain states," *Physics Reports*, vol. 918, pp. 1–133, 2021.

[3] P. J. Drew, "Neurovascular coupling: motive unknown," *Trends in neurosciences*, 2022.

[4] K. Finc, K. Bonna, X. He, D. M. Lydon-Staley, S. Kühn, W. Duch, and D. S. Bassett, "Dynamic reconfiguration of functional brain networks during working memory training," *Nature communications*, vol. 11, no. 1, p. 2435, 2020.

[5] C. Geissler, P. Gauselmann, C. Jilek, H. Maus, C. Frings, and T. Tempel, "A functional near-infrared spectroscopy study on the prefrontal correlates of cognitive offloading via a personal knowledge assistant," *Scientific Reports*, vol. 13, no. 1, p. 13938, 2023.

[6] W. Xia, R. Dai, X. Xu, B. Huai, Z. Bai, J. Zhang, M. Jin, and W. Niu, "Cortical mapping of active and passive upper limb training in stroke patients and healthy people: A functional near-infrared spectroscopy study," *Brain Research*, vol. 1788, p. 147935, 2022.

[7] A. A. Badarin, V. V. Grubov, A. V. Andreev, V. M. Antipov, and S. A. Kurkin, "Hemodynamic response in the motor cortex to execution of different types of movements," *Izvestiya VUZ. Applied Nonlinear Dynamics*, vol. 30, no. 1, pp. 96–108, 2022.

[8] V. V. Grubov, A. A. Badarin, N. S. Frolov, and E. N. Pitsik, "Analysis of real and imaginary motor activity with combined eeg and fnirs," in *Saratov Fall Meeting 2019: Computations and Data Analysis: from Nanoscale Tools to Brain Functions*, vol. 11459. SPIE, 2020, pp. 56–63.

[9] A. E. Hramov, V. Grubov, A. Badarin, V. A. Maksimenko, and A. N. Pisarchik, "Functional near-infrared spectroscopy for the classification of motor-related brain activity on the sensor-level," *Sensors*, vol. 20, no. 8, p. 2362, 2020.

[10] N. Brusinsky, A. Badarin, A. Andreev, V. Antipov, S. Kurkin, and A. Hramov, "Analysis of cognitive load in the sternberg problem: eye-tracker study," *Izvestiâ Akademii nauk SSSR. Seriâ fizičeskaâ*, vol. 87, no. 1, pp. 125–128, 2023.

[11] R. Oostenveld, P. Fries, E. Maris, and J.-M. Schoffelen, "Fieldtrip: open source software for advanced analysis of meg, eeg, and invasive electrophysiological data," *Computational intelligence and neuroscience*, vol. 2011, pp. 1–9, 2011.