Neurology, Psychiatry and Brain Research 27 (2018) 21–26

Contents lists available at ScienceDirect

Neurology, Psychiatry and Brain Research

journal homepage: www.elsevier.com/locate/npbr

Feed-forward-related neural activity for vocalization: A pilot study using magnetoencephalography

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ARTICLE INFO

Keywords:
Connectivity
Coherence
MEG
Efference copy
Corollary discharge

ABSTRACT

The present pilot study was aimed to clarifying neural activity related with the feed-forward function, sensory-motor integration processed before motor performance. Brain magnetic fields were recorded using a whole-head magnetoencephalography system before vocalization under various levels of surrounding noise in nine healthy volunteers. Participants were instructed to read a word presented on a monitor under auditory conditions with white noise of 60, 80, and 100-dB. The vocal strength of the participants significantly increased with an increase in the intensity of environmental noise. Neural connectivity associated with coherence was calculated among the vocalization-related brain areas selected: truncal area in the primary motor area (M1), premotor area (PM), supplementary motor area (SMA), posterior inferior frontal area (pIF), and posterior part of the superior temporal area (pST). Coherence between M1 and pIF in the frontal cortex without vocalization and auditory pST in the temporal area before vocalization was negatively correlated with the level of environmental noise and vocal strength, respectively. We considered that the findings in this pilot study are, at least partially, relevant to the feed-forward function for vocalization.

1. Introduction

When humans intend to perform an action, motor and sensory brain activities are controlled before the action (Wolpert & Miall, 1996). The feed-forward function was described as an automatic neural processes to control an action before actual movement, and the processes included an internal forward model used in the current state of the motor system and motor command to predict the next state (Wolpert & Miall, 1996). The feed-forward function involves a sensorimotor integration process, which can be affected by the external environment, stimuli, and internal state of brain activity at the moment of action (Perkell et al., 2007). The feed-forward process, as well as feed-back process, contributed to update and correct the motor programs with information on the external environment before and during actual movement to reach a goal of action (Medendorp, 2011).

Brain activity associated with the feed-forward function was studied using functional magnetic resonance imaging (fMRI) (Christensen et al., 2007), near-infrared spectroscopy (NIRS) (Sato, Fukuda, Oishi, & Fujii, 2012) and electro-corticography (ECoG) (Sun et al., 2015). The results in the previous studies suggested neurons in motor-associated cortices encoded sensory information before movements. An abnormal feed-forward function was also suggested in studies on the limbs and body movement of elderly persons with dementia and patients with schizophrenia and other neurological and psychological disorders, resulting in the complete loss of motor preparation and execution (Bunday & Bronstein, 2009; Elliott et al., 2010; Jo et al., 2016; Mathalon & Ford, 2008; Olafsdottir, Yoshida, Zatsiorsky, & Latash, 2007). Studies relevant to feed-forward function using a magnetoencephalography (MEG) have been carried out (Mersov, Cheyne, Jobst, & De Nil, 2017; Walla, Mayer, Deecke, & Thurner, 2004), and they reported that the premotor and motor cortices were responsible to created fluency of speech through feed-forward process. However, neural activity regarding the sensory-motor integration for the feed-forward function remains unclear.

Recently, the inter-regional relationship and functional connectivity in the neural activity in the brain have been assessed based on the advantages of analytical techniques (Sakkalis, 2011). The importance of neural activities among cortices, the brain network, has been emphasized in various brain functions (Stam & van Straaten, 2012). From the viewpoint of the brain network, inter-cortical connectivity has been investigated during and before motor performance (Muthuraman et al., 2014; O'Neill et al., 2017; Wolpert & Miall, 1996) and motor imagery (Obayashi, Uemura, & Hoshiyama, 2016). We considered that analysis of neural connectivity may provide information regarding the

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https://doi.org/10.1016/j.npbr.2017.12.006
Received 26 June 2017; Received in revised form 30 December 2017; Accepted 31 December 2017

interrelationship between sensory and motor control related to the feed-forward process, which has not been elucidated.

Controlling the vocal strength in the presence of environmental noise is known as a unique example of motor adjustment by the feed-forward function (Tartter, Gomes, & Litwin, 1993; Zollinger & Brumm, 2011). We speak loudly in a noisy environment from the first word of speech. The vocal strength is adjusted to the environmental noise condition before the vocalization by the feed-forward function. The objective of the present study was to detect brain activity related to the feed-forward function from the viewpoint of the brain network, using an experimental setting for vocalization under conditions with environmental noise. We recorded brain activity before a motor performance, vocalization, whereby the intensity might be adjusted based on the intensity of environmental noise. Since we focused on neural activity for the feed-forward function, we used a MEG system, which has the advantage of analyzing neural activity noninvasively with a high temporal resolution (Lounasmaa, Hämäläinen, Hari, & Salmelin, 1996).

Therefore, we conducted a pilot study to investigate changes in inter-cortical connectivity before vocalization in healthy subjects by changing the intensity of environmental noise using a MEG system. We reported the feed-forward-related neural activity obtained in our preliminary but challenging study in the present paper.

The efference copy and corollary discharge have been associated during the feed-forward processes (Crapse & Sommer, 2008). Since we considered that we could not clearly distinguish and extract these phenomena in the feed-forward processes, we used the term “feed-forward” to describe the neural process focused on in the present study.

2. Material and methods

2.1. Subjects

Nine healthy volunteers (5 males and 4 females, mean age: 23.6 ± 1.07 years) participated in the study. All subjects were right-handed based on the Edinburgh Inventory (Oldfield, 1971), and they had no history of neurological/psychological disorder. The present study was approved by the Ethical Committee of the Faculty of Medicine, Nagoya University.

2.2. Experimental procedure

The MEG signals were recorded in a magnetically shielded room with a whole-head MEG system (PQ-1160C, Ricoh Co., Japan) with a liquid helium recycler (HCS-MEG1, FTI, Japan). The MEG system included 160-channel axial-type first-order gradiometers with a 50-mm-long baseline detection coil. The gradiometers were arranged in a uniformly distributed array on a helmet-type dewar. Fiducial points for MEG were the nasion and both pre-auricular points, and the surface of the scalp of each subject was digitally traced using a 3-dimensional digitizer (SR system-R, Ricoh Co., Japan). The fiducial points and trace of the scalp surface were used to obtain the Montreal Neurological Institute (MNI) stereotactic coordinate for each subject, and pseudo-individual anatomy was created from standard brain anatomy, the International Consortium for Brain Mapping (ICBM) 152 non-linear atlases (Fonov, Evans, McKinstry, Almli, & Collins, 2009), using the software Brainstorm (Tadel, Baillet, Mosher, Pantazis, & Leahy, 2011). The number of vertices of the cortical surface was 15,002 in the present study on the standard brain. Further anatomical and MEG signal analyses were performed of the pseudo-individual brain. Using a pair of electrodes placed on the right hand and foot, electrocardiograms (ECG) were recorded. The MEG signals were continuously recorded with an initial bandpass filter of 0.3–2000 Hz and a notch filter of 60 Hz at a sampling rate of 5000 Hz.

Brain activity before vocalization was recorded by an MEG system under auditory conditions of environmental noise. Four conditions of artificial environmental noise involved white noise, and the noise was provided through elastic silicon tubes (3.5 mm diameter) connected to a pair of tube earphones in the participant’s ears. A pair of canal-type acoustic microphones (DEH17K, Diamond Antenna Co., Tokyo, Japan) was connected to the other side of the elastic tubes outside the magnetically shielded room. The background noise through earphones was 42 dB in the magnetically shielded room. Artificial white noise was added to the background noise, and the intensity of the noise was adjusted to 60, 80, and 100-dB earphone levels. Although the background noise did not include a specific sound but a white-noise-like sound heard through the earphones, it was different in frequency structure from the artificial noise added. Therefore, the four auditory conditions included 42 dB of background noise, and 60, 80, and 100 dB of white noise. On the center of the screen placed 45 cm in front of the subjects, one of twenty simple Japanese words in white text on a black background was presented at the center of the screen (5 × 10 cm, 6.3 × 12.5° visual field). Each word comprised 2 or 3 Japanese syllabaries, hiragana (12 and 8 words for 2 and 3 syllabaries, respectively). Pronunciation of the initial syllabary in all words was [a] in Japanese; e.g., a word [a-i] which means “love” in Japanese. All participants in a trial, environmental noise was presented for 10 s. Three seconds after the onset of the environmental noise, a word was presented on the screen for 5 s. Therefore, the environmental noise stopped 2 s after the end of the word presentation. One trial for a word with an auditory condition took 10 s. In a trial without artificial environmental noise, a word was solely presented for 5 s at same timing in a trial with environmental noise, 3 s after the onset of the trial (Fig. 1). An interval of 5 s was given between trials. Participants were instructed to read the word with natural intensity and speed of voice (Vo sequence) under the auditory conditions. When no word was presented on the screen, the participant was instructed just to watch the center of the screen for 5 s

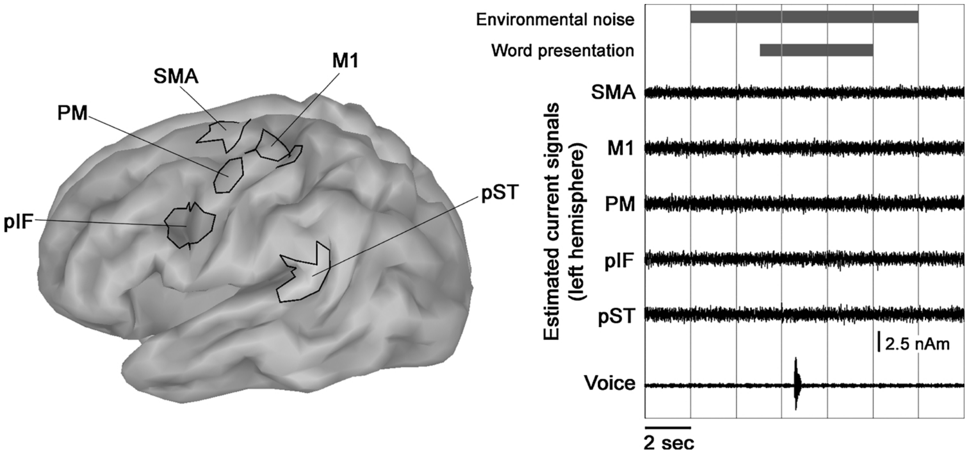

Fig. 1. Left: Brain areas selected in the left hemisphere. Truncal area in the primary motor area (M1), premotor area (PM), supplementary motor area (SMA), posterior inferior frontal area (pIF), and posterior part of the superior temporal area (pST). The areas in the right hemisphere were similarly selected. Right: Current signals estimated in each cortical areas in the left hemisphere and voice of the participant recoreded as a sonography during a trial with vocalization (voice). Timings of environmental noise and word presentation are shown horizontal bars.