【Grant-in-Aid for Scientific Research (S)】

Explorations into the Neurocognitive Basis of Symbolic Processing: Focusing on the Mediation System between Form and Meaning of Human Language

Principal Investigator	Waseda University, Faculty of Science and Engineering, Professor SAKAI Hiromu	Researcher Number:50274030
Project Information	Project Number : 23H05493 Keywords : language, thought, neural decoding, MEG, iEEG	Project Period (FY) : 2023-2027

Purpose and Background of the Research

●Why do we research symbolic processing?

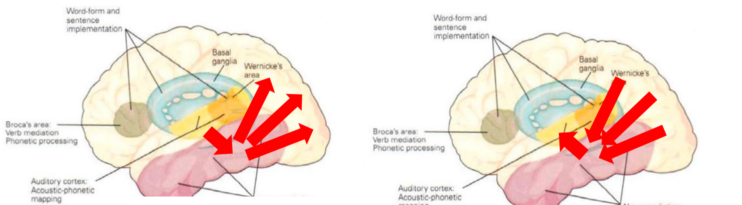
One of the reasons humans have been able to build modern society and culture is that we can use language. We can share and accumulate individual thoughts and experiences as the property of society by expressing and recording them. Linguist and philosopher F. de Saussure called systems that combine form and meaning, such as human language, "symbols," but how did only humans come to be able to use symbols? In order to unravel the secret, it is necessary to understand how the human brain processes symbols. As for human language, research to date has revealed that the brain has a region called the language areas. However, we have only discovered the location of the areas and still have little understanding of how the brain processes symbols using these areas.

●How much do we know now?

In the 21st century, research on this question has rapidly progressed in two directions. In the first direction, the "Brain Dictionary" project that comprehensively explore how meanings (or concepts) are expressed in the brain has advanced. The use of Large Language Model (LLM, which is a core of generative AIs such as ChatGPT) advanced the mapping of brain activities to meaning. In the second direction, development of systems that decode neural activities and generate forms (linguistic speech) has progressed. By recording and decoding neural activities during speech these systems are able to synthesize speech sounds like actual speech.

●What don't we know yet?

However, as research has progressed, some mysteries have deepened further. It has been found that meaning is represented in a distributed manner throughout the brain, while form is represented locally in a part of the brain called the language area. **How, then, are form and meaning, which differ in character, linked together in the brain?** The purpose of this study is to answer this question. As a clue to explore the answer, we will focus on Damasio's statement that there is a "mediation system between form and meaning" in the temporal and frontal lobes. We will also utilize the fact that phase synchronization of neural rhythms takes place when different brain regions are connected. This study aims to elucidate the function of the neurocognitive system that mediates form and meaning by measuring human brain activities and analyzing them using cutting-edge AI technology.



Mapping from Form to Meaning　　Mapping from Meaning to Form

Figure 1. Mediation system by Damasio
Representation of form is localized whereas meaning representation is distributed. They are mediated by the "hub" in the temporal lobe. (adapted from Kuhl & Damasio, 2012)

●How to proceed (MEG, iEEG, and AI)

In this study, we use magnetoencephalography (MEG), a device that can capture subtle magnetic changes caused by neuronal activities. MEG achieves excellent temporal resolution and moderate special resolution. Our team is conducting research using a unique advanced system called high-temperature superconducting self-shield MEG. However, MEG has the disadvantage that signals obtained from deep brain regions cannot be accurate. We conduct intracranial electroencephalography (iEEG) recording, which uses electrodes implanted in the skull, to get more data. Analysis of MEG data requires the extraction of patterns that represent form and meaning from a vast amount of data. To deal with this, we will incorporate an AI (machine learning) based method called "time-resolved multivariate pattern analysis".

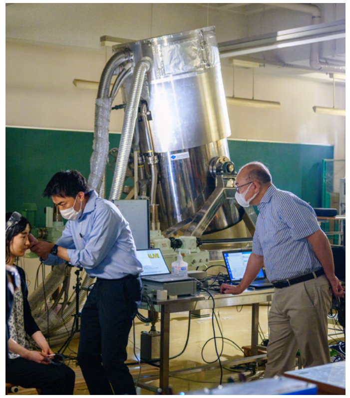


Figure 2. MEG Recording
Recording by the high-temperature superconducting self-shield MEG by Sumitomo Heavy Industry Inc.

Expected Research Achievements

●Things to be clarified during the research period

(1) Clarify the decoding accuracy of form and meaning from neural activities in both producing words from images and understanding meaning from words. We can detect the pathways connecting form and meaning in the brain by comparing when AI learns by the "meaning (image) to form (word)" route and when it learns by the "form to meaning" route and finding out where both routes intersect.
(2) During decoding, we map and visualize how accurately form and meaning can be decoded from MEG signals measured in each area of the brain. This reveals the position of the pathways connecting form and meaning.
(3) For each area of the brain along the pathway, we calculate how much neural rhythm is synchronized between areas. This reveals the strength and the timing of the neural connections in the brain.

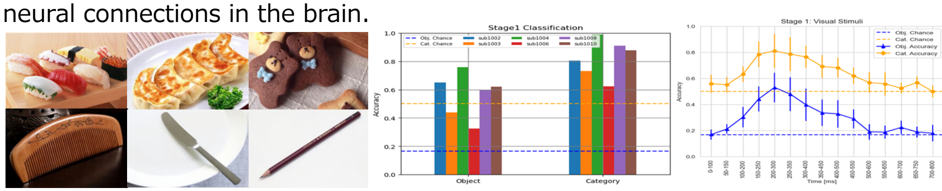


Figure 3. Results of having the AI predict which image the participants were looking at when they were presented with six different pictures. The accuracy ranges over 60%-80% though there are variations among participants. Temporal changes in the accuracy can also be explored.

●Future possibilities

One day we become able to create a system to support people with communication disabilities by synthesizing their speech from neural activities. It might become possible to express thoughts and ideas through neural signals without using language.

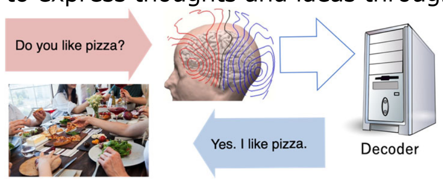


Figure 4. Conversation System using Brain Decoding
If neural activities can be decoded in real-time by AI, a communication system based on neural activities will become possible. However, various issues remain to be solved, including the development of a compact and low-cost neural activity measurement device.

Homepage Address, etc.	http://www.blit.sci.waseda.ac.jp https://researchmap.jp/read0186063