Brain activation in an intermediate-level Japanese learner
– Correlation analysis of fNIRS data during written tests and conversation –

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Abstract
This study is part of a project that aims to examine the similarity and/or dissimilarity in brain activation while participants take written tests and make conversation. Brain activation data were collected from one intermediate-level Japanese learner, and trend chart analysis and correlation analysis were conducted. Some common brain activation patterns were also observed in this participant throughout the project, such as hemispheric dominance for language tasks, and greater activation for conversation tasks than written test tasks. In addition, the trend chart analysis revealed that the deoxyhemoglobin data increased more than the oxyhemoglobin data around Broca's area in some cases. The correlation analysis revealed that the translation task and the dialogue completion task had the most number of channels, exhibiting a strong correlation with (i.e. similarity to) the Japanese conversation task. In a consolidated discussion referring to the present author's previous study, the peculiarity of the deoxyhemoglobin data were also pointed out. This project is still at the stage of seeking better ways to judge similarity (or dissimilarity), but it is suggested in this study that the use of correlation analysis results in intriguing observations, which lead to formulation of a hypothesis about the developmental stages of the L2 system.

1. Introduction

In modern-day language teaching, it is apparent that practical communicative proficiency, rather than enhancement of the learner's grammatical knowledge, has become the first priority (in most cases). Despite the emphasis on communication skills, however, we still have to heavily rely on written tests to assess achievement of teaching/learning in class. This is due to various practical reasons such as a large number of students (i.e., time constraint) and the intrinsic difficulty in assessing conversation skills (e.g., the standardization issue and the need for teacher training).[1] Usually, the validity and reliability of written tests have been examined by test score statistics.[2] However, high scores on written tests do not necessarily correspond to high communicative proficiency.

If we can use written tests to assess and/or promote a learner's communicative proficiency, it provides a significant benefit for language courses. What kind of written tests, if any, can be used for such purposes? Is there any written test format that induces brain activation similar to that of conversation? To attempt to answer these questions, it is necessary to examine similarity and/or dissimilarity in brain activation during written tests and conversation. This is the objective of a long-term project, and this study is a part of that project.

Below is a summary of the findings of the project discussed in Hirata (2013a, 2013b, 2014a, 2014b, 2014c). In the first year of the project, four beginner-level and three intermediate-level learners participated in a brain imaging experiment. In the second year, there were 11 participants ("subjects") in the experiment, comprising two beginner-level and nine intermediate-level learners. All findings and observations below are those of right-handed participants unless otherwise noted. As for the written test tasks, the following four types were examined: multiple choice 1 (three choices for one blank), multiple choice 2 (three choices for three blanks), translation, and dialogue completion. The experimental design and procedure are explained in Section 2 of this paper.

(1) The trend analysis charts show that both beginner-level and intermediate-level learners exhibit a high degree of brain activation during the conversation tasks. In comparison, brain activation during the written tasks is not very high.

(2) Written tasks of the same format do not necessarily exhibit the same brain activation pattern in terms of the location and degree; the degree of difficulty and the content of the task seem to be critical factors.

(3) Likewise, conversation tasks exhibit different brain activation patterns depending on the participant's Japanese proficiency level and the content of the conversation. In addition, the degree of activation may be significantly different depending on those factors.

(4) Overall, intermediate-level learners show a higher degree of brain activation during conversation tasks than during written tasks.

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[1] Regarding the difficulty in assessing conversation skills, see Bachman and Savignon (1986) and Brown (2005). Regarding the Japanese ACTFL OPI (American Council on the Teaching of Foreign Languages Oral Proficiency Interview), see Makino *et al*. (2001). For assessing speaking in general, see Luoma (2004).

[2] See Bachman (1990), Bachman and Palmer (1996), Otomo and Nakamura (2002), Hughes (2002), Kondo-Brown (2012), and others.

(5) Some beginner-level learners show about the same degree of brain activation during conversation tasks and written tasks.

(6) Intermediate-level learners show about the same degree of brain activation in the right and left hemispheres during conversation tasks. During written tasks, however, the left hemisphere is more activated than the right hemisphere.

(7) In beginner-level learners, the degree of brain activation in Broca's area shows similarity in the following task pairs: [three-choice coordination vs. translation], [translation vs. dialogue completion], and [three-choice coordination vs. Japanese conversation]. The "similarity" here means that the difference in the degree of brain activation, tested with ANOVA (analysis of variance), is not statistically significant. Only one intermediate-level learner showed similarity in two task pairs. This could be because her conversational proficiency was not high.

To summarize the above findings further, it can be said that brain activation during written tasks and conversation tasks is quite complex and exhibits a large degree of variation dependent on individual and task differences. The complexity of the research topic has now become more concrete and clear. To establish a research framework is a continuous theme of the project, and the following set of items has become apparent during the course of this project:

(8) Which channel (or a set of channels) to choose for analysis. (The "channels" are the measurement points.)

(9) How to address the differences among tasks of the same format due to different degrees of difficulty. Given the difference, which task should be selected for analysis.

(10) How to process data for analysis, e.g., processing by each task, or using mean values for a certain set of tasks.

(11) Which data to use for analysis, oxy- or deoxyhemoglobin data.

(12) How to address the participants' individual differences, such as first language, handedness, reading skills, and conversation skills.[3]

To seek a better research design, several adjustments and attempts have been made, such as: (a) increasing the number of repetitions of tasks of the same format, (b) including Wernicke's area in addition to Broca's area, (c) analyzing data separately for each individual participant (i.e., in contrast to averaging the data from participants in the same categories such as proficiency levels and first languages), and (d) employing ANOVA for examining similarity between tasks of different formats.

While ANOVA compares the mean values of the brain activation data, Hirata (2015), as a

[3] Handedness is strongly related to the location of language processing. Right-handed individuals usually have Broca's area in the left hemisphere, but left-handed individuals may have it in the right hemisphere or in both hemispheres in some cases.

new attempt, examined the similarity of activation patterns using correlation analysis. In that study, the data collected from one beginner-level learner were analyzed. As a continuous, cumulative study, this paper applies correlation analysis to the data from one intermediate level learner, and then discusses the results of the beginner- and intermediate-level learners together. In most cases, past studies in this field discussed where L1 and L2 were processed (i.e., locations of brain activation) or the degree of activation using the mean values of brain imaging data. In contrast, the use of correlation analysis in the current and the previous paper analyze the activation pattern (i.e., trends) at each measurement point.

In general, as the number of participants, tasks, and channels increases, brain-imaging data, including those from functional near-infrared spectroscopy (fNIRS) in this study, increase significantly (i.e., being multiplied by the numbers of participants, tasks, and channels). When analyzing the fNIRS data, it is necessary to perform preparatory processing, such as segmentation, extraction, baseline adjustment, and TEXT file conversion. Only after such processes can the data be analyzed with Microsoft EXCEL, or statistical software such as SPSS. This requires a significant amount of time, and only a limited set of data can be analyzed at a time.

Using brain-imaging techniques for studying brain and language is a rather new field. Since a pioneering study by Petersen *et al.* (1988), however, its range of applications has expanded. For example, the study by Scherer *et al.* (2006) is an example of a bilingualism study. Amiri *et al.* (2014) studied the relationship between aging and semantic processing. Horowitz-Kraus *et al.* (2014) investigated reading acceleration training in children with reading difficulties.

The relationships between language proficiency and lateralization of brain function are commonly studied in the field of bilingualism and second language acquisition. For example, Illes *et al.* (1999) reported no statistically significant differences in the location of the brain that was activated when advanced speakers of both English and Spanish spoke English or Spanish. Furthermore, Perani *et al.* (2005) disagree with the hypothesis that L1 and L2 are processed in different regions of a bilingual brain. As for foreign language learning, Oishi (2006) reported that the left hemisphere was more activated than the right hemisphere for advanced learners of English, while there was no such difference for beginner-level learners. She argued for the hypothesis that the left hemisphere would become dominant in processing L2 as learners become more proficient.

These past studies can be categorized into two major types. One examines the lateralization of brain function (e.g., Joo 1997; Scherer *et al.* 2006; Osaka 2007). In this type of study, participants of the same category (e.g., the same gender, age group, L1, and proficiency) are asked to do different kinds of language tasks. The other type of study investigates differences between different groups of participants (i.e., language users), e.g., [intermediate-level learner vs. advanced-level learner], [language use in schizophrenia], and [various types of bilingual speakers] (e.g., Oishi 2002; Kubota *et al*. 2005; Taura and Nasu 2012; Andrews *et al*. 2013). To put it simply, these two common types of research investigate brain function and particular language users.

In contrast, the objective of this project is to investigate the nature of language tasks, namely written tests and conversation tasks, by using brain-imaging technology. This is a new application of brain-imaging technology to research foreign language teaching.

2. Methods

2.1. Overview

The participants in the experiment were asked to do several types of written test tasks and two types of conversation tasks. During the experiment, the participants' brain activation data were recorded by an fNIRS system. The activation patterns are first acquired visually using trend analysis charts. Next, the correlation analysis is applied to the data of 14 channels to examine the similarity between written tasks and Japanese conversation tasks. Details about the fNIRS system, the participants, task design, experimental procedure, and analytical procedure are explained below.

2.2. fNIRS

For brain imaging, this project has been using FOIRE-3000, a fNIRS systems made by SHIMADZU. There are several other types of brain imaging methods, such as PET (Positron Emission Tomography), fMRI (Functional Magnetic Resonance Imaging), and MEG (Magnetoencephalography). Each method has different spatial resolution, temporal resolution, invasiveness, cost, and other features. This project uses fNIRS for the following three reasons: (1) it is noninvasive and safe, (2) it is quiet, and (3) participants can move freely (compared to the other systems), which is desirable for language tasks. It should be noted that the spatial resolution of fNIRS is low, although its temporal resolution is high. The measurement channels are three centimeters apart horizontally, and it is difficult to identify the exact location within the brain. As for the temporal resolution, fNIRS can collect data within the interval of less than one second. For example, the present study used the data collecting frequency of every 1/100 of a second.

Figure-1 below shows an fNIRS system image.[4] The participant wears headgear with many holes into which fiber-optic probes are set. The headgear and the fNIRS equipment are physically connected by these probes during the experiments. The fNIRS equipment works with a PC with the fNIRS application installed.

Figure-1 fNIRS system image

Figure-2 Example of channel arrangement

Figure-2 above shows an example of how the measurement channels correspond to the locations on the head. The fNIRS system uses two types of fiber-optic probes, namely, emitters and detectors. In FOIRE-3000, the emitters and detectors are colored red and blue, respectively, although this is not clear in Figure-2 due to the gray scale. The emitters and detectors are set

[4] With permission, this is taken from the SHIMAZU website.

side-by-side into the headgear, with a separation distance of three centimeters. The white boxes in Figure-2 indicate the locations of measurement channels. The channels are physical locations between emitters and detectors.

The experiment in this paper used 15 emitters and detectors, and there are 39 channels. Figure-3 below shows the channel arrangement of this experiment.

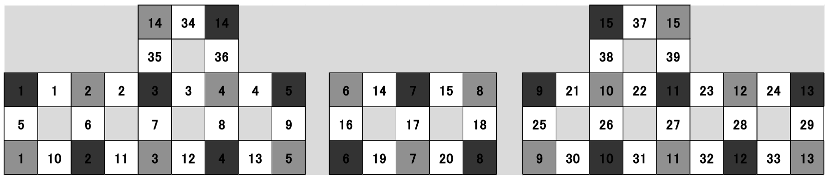

Figure-3 Channel arrangement

Figure-4 below shows how each channel for the left hemisphere corresponds to the physical location on the brain (using an explanatory figure of the International 10/20 system),[5] and Figure-5 shows the locations of Broca's area and Wernicke's area.[6] This is a typical case for right-handers for whom the left hemisphere is dominant for language processing.

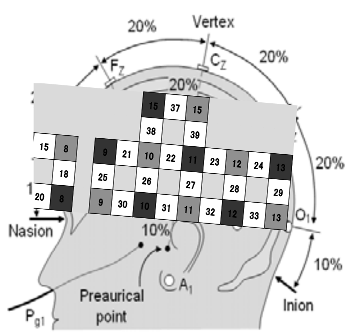

Figure-4 Channels on the left hemisphere

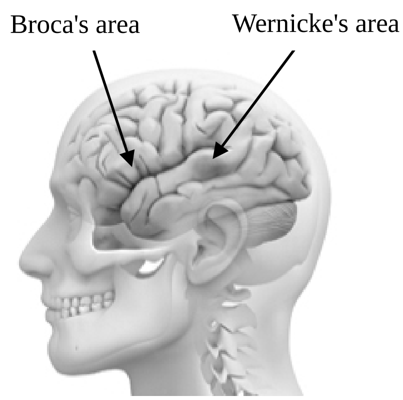

Figure-5 Broca's area and Wernicke's area

In the past, Broca's area was thought to function in language production, while Wernicke's area was thought to function in comprehension. In recent years, however, many researchers have stated that brain regions are not exclusively dedicated to specific functions, but instead work together for particular functions.[7] Nevertheless, Broca's area and Wernicke's area are regarded as important regions for language processing. In a typical case in this particular study, Broca's area corresponds to the area around Channel 25 and 26 in Figure-3 and 4, and Wernicke's area to the area around Channel 27. Exact channel correspondence depends on how the headgear fits on

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[5] As seen in Figure-4, either 10% or 20% of the distance between the data points are used for determining the location of electrodes in the International 10/20 (or 10-20) system.

[6] Figure-5: http://www.automatesintelligents.com/biblionet/2008/jan/neuroneslecture.html

[7] See Obler and Gjerlow (1999), Sakai *et al*. (2001), and Sakai (2002).

each subject's head, and is judged individually.

fNIRS data are the products of the change in blood concentration and the optical path length, and are presented using the unit of mmol.mm (millimole per liter-millimeters). There are three types of data, namely oxygenated hemoglobin (hereafter "oxy-Hb"), deoxygenated hemoglobin (hereafter "deoxy-Hb"), and the sum of these two, total hemoglobin (hereafter "total-Hb").[8]

2.3. Participants

As explained above, it takes a lot of time to analyze fNIRS data of significant size (e.g., several types of tasks done by many participants). Thus, as a continuous, cumulative study from the previous one, this paper applies correlation analysis to the data from one intermediate-level learner. She was one of the 18 Japanese learners (eight beginner-level and ten intermediate-level learners) who participated in the project in that particular year.[9] They were international college students participating in a short-term Japanese study-abroad program. Her data were chosen for analysis because of her level of proficiency in Japanese and her first language. These intermediate-level participants were at the second highest level in the Japanese program. Roughly speaking, these classes are a little below the N2 level on the JLPT scale (JLPT: Japanese Language Proficiency Test).

The handedness of each participant was assessed using the Edinburgh handedness inventory (i.e., the laterality index based on writing, throwing, scissors, toothbrush, and so on), and the focal participant in this paper was 100% left-handed. Table-1 below provides information about the participant.

Table-1 Participant information

Gender	Female	Length of studying Japanese	6 years 6 months
Age	21	Proficiency Level	Intermediate
Nationality	New Zealand	Foreign languages other than Japanese	None
1st Language	English	Handedness	Left-handed

2.4. Task Design

This study examined the following four written test task types: (a) multiple choice 1 (three choices for one blank; hereafter "three-choice"), (b) multiple choice 2 (three choices for three blanks; hereafter "three-choice coordination"), (c) translation, and (d) dialogue completion. The fourth type, dialogue completion, is not as common in Japanese courses, but it is the type of written test that the present author has been using in class to improve leaners' conversation skills. As for the conversations tasks, this study examined both L2 (i.e., Japanese) and L1 (i.e., English) conversation tasks.

It is very important to keep the overall experiment time to less than one hour (even for adults) since there is a lot of mental and physical stress on the participant during the experiment, especially due to wearing uncomfortable headgear. After a participant enters the experiment room, it usually takes about thirty minutes for equipment setup (i.e., headgear and probes) and questionnaire completion. Thus, the actual time to complete the language tasks should be about

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[8] The brain consumes a lot of oxygen when it is working. So, when a certain portion of the brain becomes highly activated, oxygenated hemoglobin, which carries oxygen, comes into the area more and more. Then, the oxygen is consumed there, and the oxygenated hemoglobin changes to deoxygenated hemoglobin.

[9] This experiment was approved by the Ritsumeikan human research ethics committee.

thirty minutes.

Table-2 below shows the overall task design. Considering various conditions such as individual task time, the number of tasks of the same format completed, and the rest time, the overall task configuration was designed. Table-2 only contains information about the actual language tasks, but an explanatory example is presented before each type of task. There are also thirty-second rest sessions before and after each task.[10]

2.5. Procedure

2.5.1. Experiment

Except for the last four conversation tasks, the participants were given a booklet of paper tasks to keep the experiment process as close as possible to the actual in-class written tests. Instead of using the automated task control in FOIRE-3000, an fNIRS system, the data were recorded continuously and the present author placed the start and end markings manually on the data for each task. This was because this particular experiment was a set of paper-based tasks, and not synchronized with the system on the computer. Each paper task was timed by PowerPoint, and the participants were instructed to move on to the next page when the PowerPoint slide chime was heard. Compared to the usual brain experiment tasks, the duration of time given for each task in this experiment was rather long, and the participants may have finished tasks earlier than the planned time. When the participant finished a certain task earlier, this was marked manually on the data. The conversation tasks were also timed by PowerPoint, and there was no visual prompt for conversation; the present author initiated each conversation by talking to the participants.

Table-2 Overall task design

	Language Tasks	
TASK01	Three-choice 1	30 sec.
TASK02	Three-choice 2	30 sec.
TASK03	Three-choice 3	30 sec.
TASK04	Three-choice coordination 1	50 sec.
TASK05	Three-choice coordination 2	50 sec.
TASK06	Three-choice coordination 3	50 sec.
TASK07	Translation 1	30 sec.
TASK08	Translation 2	30 sec.
TASK09	Translation 3	30 sec.
TASK10	Discourse completion 1	1 min.
TASK11	Discourse completion 2	1 min.
TASK12	Japanese conversation 1	1 min.
TASK13	Japanese conversation 2	1 min.
TASK14	English conversation 1	1 min.
TASK15	English conversation 2	1 min.

FOIRE-3000 was synchronized with a video camera, and the entire experiment was video-recorded. When necessary, the video data were used to confirm if the experiment was carried out properly. In addition, the conversation tasks were recorded with an IC recorder, which was used to judge the participant’s conversational proficiency.

2.5.2. Analyses

This study conducted two types of analyses. First, the activation patterns were acquired visually by the use of trend analysis charts, which were provided by FOIRE-3000. There were 15 language tasks in the experiment, and there was one trend chart screen for each task, hence 15

[10] The task design of this study does not employ so-called “cognitive subtraction.” Since a pioneering study by Petersen et al. (1988), “cognitive subtraction” has been commonly employed in brain experiments. In such an experimental design, it is assumed that differences in data between an experimental state and a control state are induced by a particular cognitive process, e.g., [experiment state A+B+C]-[control state A+B] = [target state C]. One reason for the non-use of the cognitive subtraction technique is that the language tasks in this study require complex cognitive processes, which are difficult to decompose. It should also be noted that there are many scholars who claim that cognitive processes are not module-like or addable (e.g., Friston et al. 1996, Wagner 1999).

screens in total. A total of six screens, one screen for each task type, are presented in this paper (see Figure-7 below); these screen shots showed the greatest brain activation around Broca's area and Wernicke's area among the tasks of the same format.

Next, the correlation analysis was applied to the data of those six tasks, one from each task type (i.e., in this study, the Pearson product-moment correlation coefficient was calculated using IBM SPSS 22). Due to the data size, seven channels around typical Broca's area and Wernicke's area, as well as the seven channels on the other side of the head, were chosen for analysis; there are 14 channels in total. Figure-6 below shows the target channels.

As noted above, the correlation analysis was applied to all six types of tasks, namely, three-choice, three-choice coordination, translation, dialogue completion, Japanese conversation, and English conversation. Instead of all possible combinations, however, the correlation with the Japanese conversation task was examined. It should also be noted that only the data from the same channel were compared, e.g., [Three-choice Channel 25] vs. [Japanese conversation Channel 25].[11]

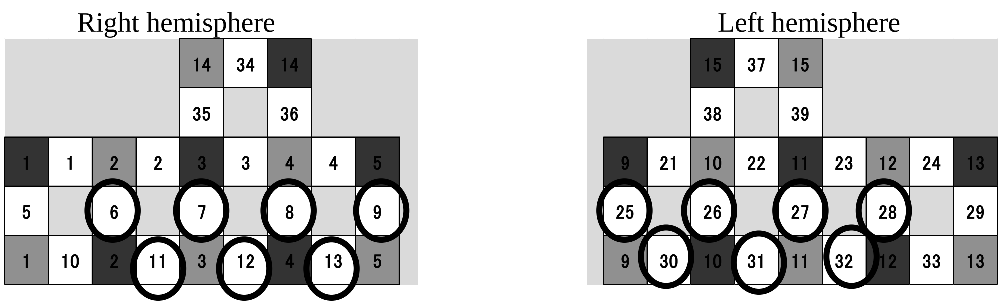


Figure-6 Target channels for correlation analysis
(CH6, 7, 8, 9, 11, 12, 13, 25, 26, 27, 28, 30, 31, 32)

A summary of the combinations for analysis is as follows (“CH” = “channel”):

[Three-choice CH 6] vs. [Japanese conversation CH 6], and remaining 13 channel pairs.
[Three-choice coordination CH 6] vs. [Japanese conversation CH 6], … (14 pairs in total).
[Translation CH 6] vs. [Japanese conversation CH 6], … (14 pairs in total).
[Discourse completion CH 6] vs. [Japanese conversation CH 6], … (14 pairs in total).
[English conversation CH 6] vs. [Japanese conversation CH 6], … (14 pairs in total).

Regarding the oxy-Hb data and deoxy-Hb data, this study examined both types of data. In past studies, some scholars used oxy-Hb for brain activation analysis (e.g., Tamura 2002; Shimoyama *et al.* 2006; Toronov *et al.* 2007; Leung 2008; Malonek *et al.* 1997; Strangman *et al.* 2002; Fukuda 2009). In the present author’s past studies, however, the deoxy-Hb data seemed to reflect brain activation in some cases. Therefore, Hirata (2015), the current author’s previous study, included deoxy-Hb data for correlation analysis. This study also examined both types of data as a continuous, cumulative study.

[11] As explained above, fNIRS data are the products of the change in blood concentration and the optical path length. Since the optical path length is different depending on the channel location (plus, complex reflections), we have to be careful when dealing with the data.

3. Results and observations

3.1. Trend charts

Figure-7 below shows six screen images of the six types of the tasks. Each screen has 39 trend charts of 39 channels for this study.

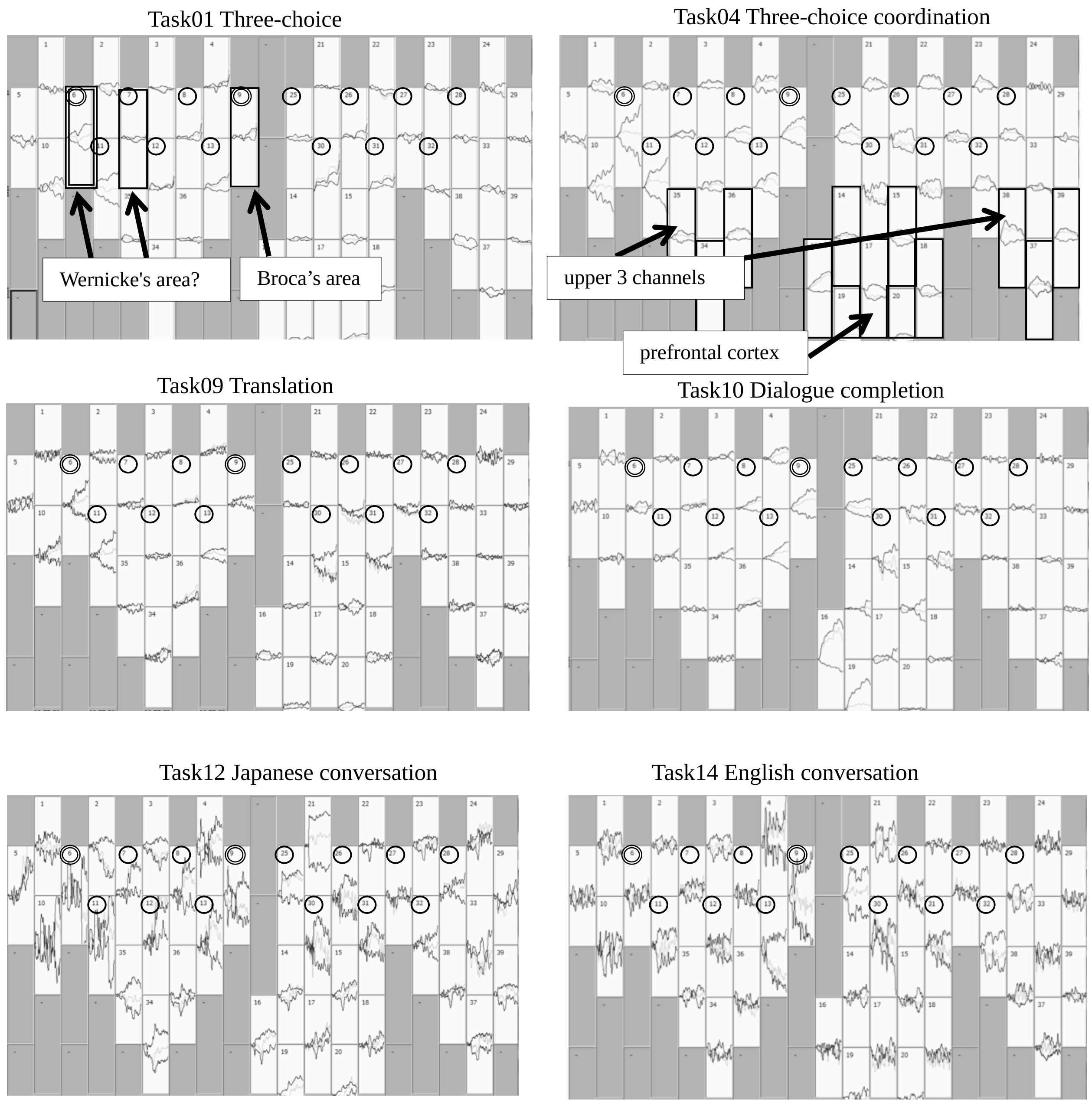


Figure-7 Trend charts of the six different tasks

The 14 target channels for correlation analysis (i.e., Channel 6-9 and 11-13 on the right hemisphere and Channel 25-28 and 30-32 on the left hemisphere) are indicated with bold circles on the channel numbers in the six screen images. Among those 14 channels, Channel 6 and 9 are marked with double circles because the former seems to correspond to Wernicke's area, the latter to Broca's area.

Due to software limitations, Channel 34-36, which are upper three channels on the right hemisphere, Channel 37-39, which are upper three channels on the left hemisphere, and Channel 14-20, which are seven channels on the front prefrontal cortex, are placed in rather odd places on the screens, as shown on the screen image for Task04 (on the first row, right-hand side).

We can observe the change of fNIRS data in real time on the screen during the experiment. On the actual screen, the oxy-Hb data are shown in red, the deoxy-Hb data in blue, and the total-Hb data in green. However, the charts are presented in a gray scale in this paper, so it is difficult to distinguish the three graph lines. For this participant, the graph lines for the oxy-Hb data were higher than those for the deoxy-Hb data in most cases. Some of the notable exceptions are Channel 9 for the translation task and the English conversation task, and Channel 25 for the Japanese conversation task and the English conversation task, in which the deoxy-Hb data were greater than the oxy-Hb data.

Below are observations from the trend charts above:

(13) Regarding this particular participant, who is left-handed, the right hemisphere seems to be more activated during the language tasks than the left hemisphere. Based on visual judgment of the degree of brain activation, it seems most likely that Channel 9 corresponds to Broca's area, and Channel 6 to Wernicke's area.

(14) If we compare the written tasks (the former four tasks) and the conversation tasks (the latter two tasks), brain activation is more significant for the conversation tasks than the written tasks. To be more specific, going up and down the graph lines for the conversation tasks is noticeably rapid.

(15) It is clear that Broca's area (Channel 9) and Wernicke's area (Channel 6) work differently for different language tasks.

(16) The trend charts for Broca's area (Channel 9) show increases of the oxy-Hb data (originally shown with a red graph line) and decreases in the deoxy-Hb data (originally shown with a blue graph line) for Task01 (Three-choice), Task04 (Three-choice coordination), and Task10 (Dialogue completion). In contrast, Task09 (Translation) and Task14 (English conversation) exhibit the opposite pattern, i.e., increase of deoxy-Hb and decrease of oxy-Hb. Task12 (Japanese conversation) shows a complex pattern. The deoxy-Hb data increased and the oxy-Hb data decreased rapidly at the beginning, and then their trends reversed, i.e., rapid increase of oxy-Hb and rapid decrease of deoxy-Hb.

(17) The trend charts for Wernicke's area (Channel 6) show increases in the oxy-Hb data and decreases in the deoxy-Hb data for Task01 (Three-choice), Task04 (Three-choice coordination), Task09 (Translation), and Task12 (Japanese conversation). In contrast, Task10 (Dialogue completion) and Task14 (English conversation) exhibit the opposite pattern, i.e., increase of deoxy-Hb and decrease of oxy-Hb.

3.2. The correlation analysis

As explained above, each task (i.e., three-choice, three-choice coordination, translation, dialogue completion, and English conversation) was compared with the Japanese conversation task. There are 14 target channels from each task, and the data from the same channels were compared, e.g., [Three-choice CH6 vs. Japanese conversation CH6], [Translation CH9 vs. Japanese conversation CH9], … and [English conversation CH32 vs. Japanese conversation CH32]. The two types of data, oxy-Hb and deoxy-Hb, were examined. Below are the results which show a strong correlation (i.e., 0.7 < | r | < 1.0; r = Pearson's correlation coefficient). Table-3 is for the oxy-Hb data and Table-4 for the deoxy-Hb data. The items with a negative correlation are shaded.

Table-3 Channels exhibiting a strong correlation (oxy-Hb)

Task combination	Channels of strong correlation (oxy-Hb)
Three-choice vs. Japanese conversation	CH8 (r=.953, p<.001), CH13 (r=.828, p<.001), CH28 (r= -.826, p<.001)
Three-choice coordination vs. Japanese conversation	None
Translation vs. Japanese conversation	CH8 (r=.855, p<.001), CH12 (r=.788, p<.001), CH13 (r=.831, p<.001)
Dialogue completion vs. Japanese conversation	CH8 (r=.850, p<.001), CH11 (r=.761, p<.001), CH27 (r=.706, p<.001)
English conversation vs. Japanese conversation	None

Table-4 Channels exhibiting a strong correlation (deoxy-Hb)

Task combination	Channels of strong correlation (Deoxy-Hb)
Three-choice vs. Japanese conversation	None
Three-choice coordination vs. Japanese conversation	CH25 (r= -.712, p<.001)
Translation vs. Japanese conversation	CH7 (r=.886, p<.001), CH25 (r= -.774, p<.001), CH32 (r=.834, p<.001)
Dialogue completion vs. Japanese conversation	CH11 (r=.848, p<.001)
English conversation vs. Japanese conversation	CH12 (r= -.715, p<.001), CH13 (r= -.771, p<.001), CH25 (r=.794, p<.001)

We can observe the following:

(18) In relation to the Japanese conversation task in the oxy-Hb data, the highest number of channels exhibiting a strong positive correlation is three, and they are observable in [Translation vs. Japanese conversation] and [Dialogue completion vs. Japanese conversation].

(19) As for the oxy-Hb data, the three-choice coordination task and the English conversation task did not show a strong positive correlation to Japanese conversation task at any channel. Likewise, the three-choice task in the deoxy-Hb data did not show a strong positive correlation to the Japanese conversation task at any channel.

(20) There was a strong negative correlation in the oxy-Hb data from only one channel, while

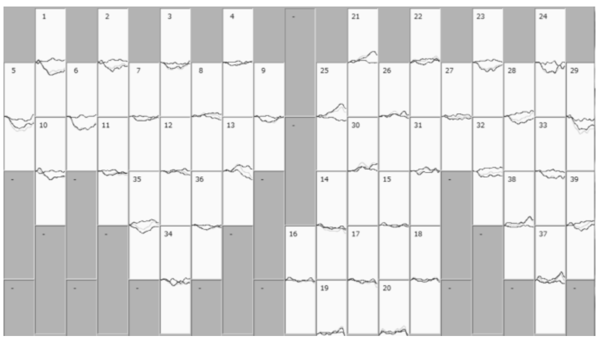
four out of eight channels showed strong negative correlations in the deoxy-Hb data.

(21) Regarding the right and left hemisphere differences, most channels with a strong positive correlation in the oxy-Hb data belonged to the right hemisphere (from CH6 to CH13), where the participant's language regions are thought to reside.

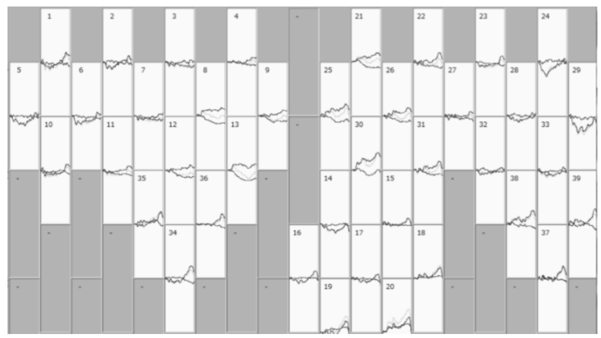
4. Discussion

In a previous study, Hirata (2015) examined the data from one beginner-level learner, whereas this study examined the data collected from one intermediate-level learner. Here the results of the two participants are discussed together. Figure-8 below provides six screen images of the trend charts from Hirata (2015). Based on the Edinburgh handedness inventory, the participant was judged to be 71% right-handed.[12]

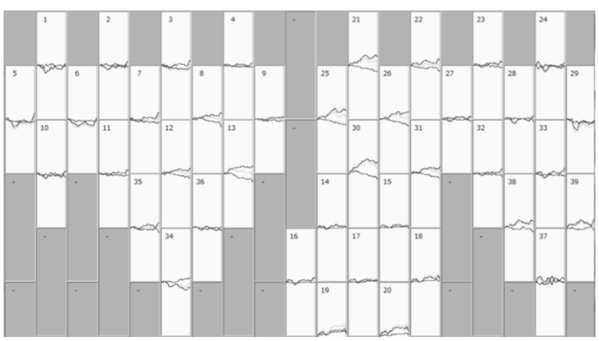
Task03 Three-choice



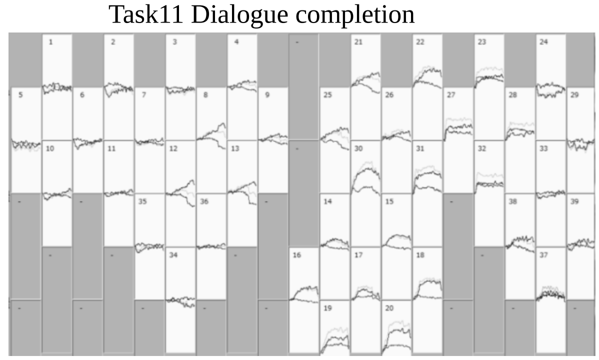
Task04 Three-choice coordination



Task08 Translation



Task11 Dialogue completion



[12] This percentage is called "Laterality Quotient (LQ)," which is calculated with the following formula: LQ = [(R-L)/(R+L)] * 100. The "R" in this formula stands for the number of responses executed using the right hand for the Edinburgh handedness questionnaire, and the "L" for those executed using the left hand.

Task12 Japanese conversation　　　　Task14 English conversation

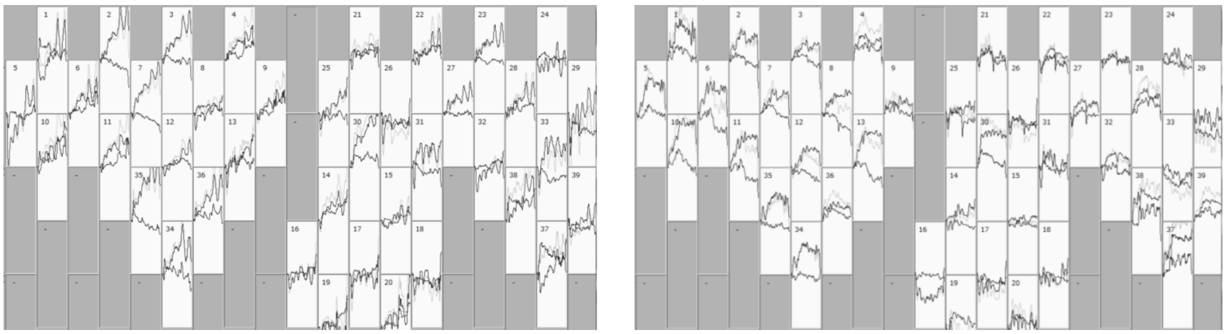


Figure-8 Trend charts of the six different tasks (a beginner-level learner from Hirata 2015)

Both Figure-7 and -8 agree with the results of the present author's past studies in that the degree of brain activation for conversation tasks was significantly higher than that for written tasks. In addition, it seems that the degree of brain activation for three-choice tasks was the lowest among different types of written tasks. Further, the same feature is observable for the conversation tasks; the rise and dip of the graph lines is markedly rapid. This may suggest that the brain activation is not simply a matter of increase of blood flow, but rather a degree of change. The oxy-Hb data values were generally higher during the language tasks for the beginner-level learner while the deoxy-Hb data behaved differently for the intermediate-level learner.

Next, let us compare the results of the correlation analysis. Table-5 is a summary table for the oxy-Hb data, and Table-6 for the deoxy-Hb data (translated and slightly modified from Hirata 2015).

Table-5 Channels exhibiting a strong correlation (oxy-Hb)

(a beginner-level learner from Hirata 2015)

Task combination	Channels with a strong correlation (oxy-Hb)
Three-choice vs. Japanese conversation	CH12 (r=.782, p<.001), CH13 (r=.706, p<.001), CH30 (r=.909, p<.001),
Three-choice coordination vs. Japanese conversation	CH12 (r=.712, p<.001), CH13 (r=.731, p<.001), CH25 (r=.766, p<.001), CH26 (r=.725, p<.001), CH30 (r=.955, p<.001),
Translation vs. Japanese conversation	CH30 (r=.928, p<.001), CH31 (r=.781, p<.001),
Dialogue completion vs. Japanese conversation	CH27 (r=.718, p<.001), CH30 (r=.899, p<.001),
English conversation vs. Japanese conversation	CH6 (r=.848, p<.001), CH7 (r=.916, p<.001), CH11 (r=.873, p<.001), CH12 (r=.801, p<.001), CH13 (r=.712, p<.001), CH25 (r=.779, p<.001), CH26 (r=.790, p<.001), CH27 (r=.787, p<.001), CH28 (r=.752, p<.001), CH30 (r=.905, p<.001), CH31 (r=.927, p<.001),

Table-6 Channels exhibiting a strong correlation (deoxy-Hb)
(a beginner-level learner from Hirata 2015)

Task combination	Channels with a strong correlation (deoxy-Hb)
Three-choice vs. Japanese conversation	CH12 (r= -.738, p<.001), CH32 (r=.745, p<.001)
Three-choice coordination vs. Japanese conversation	CH12 (r= -.765, p<.001), CH13 (r= -.770, p<.001)
Translation vs. Japanese conversation	CH9 (r= -.732, p<.001), CH12 (r= -.804, p<.001), CH13 (r= -.751, p<.001), CH31 (r=.951, p<.001)
Dialogue completion vs. Japanese conversation	CH28 (r=.716, p<.001)
English conversation vs. Japanese conversation	CH30 (r=.777, p<.001), CH32 (r=.805, p<.001)

If we compare Table-3, 4, 5, and 6, it is immediately noticeable that, compared with the intermediate-level learner, the beginner-level learner has more channels for which there is a strong correlation. The most peculiar case is the comparison between the English conversation task and the Japanese conversation task, using the oxy-Hb data. While there are 11 channels that exhibit a strong correlation for the beginner-level learner, no channel exhibits this correlation pattern for the intermediate-level learner. Moreover, there are two other tasks that have no strong correlation with the Japanese conversation task, specifically the three-choice coordination task using the oxy-Hb data, and the three-choice task using the oxy-Hb data.

The above observation is, in fact, a little puzzling. If we judge the degree of similarity of brain activation based on the number of channels that exhibit strong correlation, the data suggest that brain activity for a Japanese conversation task and an English conversation task is more similar for a beginner-level learner, than for an intermediate-level learner. This seems to disagree with our natural assumption and some results from past studies, indicating that L2 language processing becomes closer to L1 processing as learners become more proficient (e.g., Illes *et al*. 1999; Perani *et al*. 2005; and Oishi 2006). Those claims in the past studies are based on the discussion about where L1 and L2 are processed (i.e., locations of brain activation), or about the degree of activation using the mean values of brain imaging data. In contrast, the use of correlation analysis in the current and the previous paper, analyzed the activation pattern (i.e., trends) at each measurement point.

If the results shown in this paper are valid, one possible hypothesis would be that beginner-level learners cannot develop a different processing system for L2, until they reach a certain point in the learning process, and the L2 system gradually develops and diverges from the L1 system. In any case, it is too early to draw a conclusion at this point, and it is necessary to analyze data from more individuals using correlation analysis.

We may also need to consider the channels that exhibit a strong negative correlation when looking at Tables-3, 4, 5, and 6. The deoxy-Hb data, in contrast to the oxy-Hb data, displayed strong negative correlations at more channels for both the beginner- and intermediate-level learners. The strong negative correlation is especially noticeable for the written test tasks, with the deoxy-Hb data for the beginner-level learner. We cannot generalize these observations yet, but it seems worthwhile to continue analyzing brain activation using the deoxy-Hb data; it might provide more informative results than the oxy-Hb data alone.

5. Conclusion

This study analyzed the fNIRS data collected from one intermediate-level learner. Two types of analyses were conducted. First, the activation patterns were acquired visually using trend analysis charts, and then correlation analysis was applied. Lastly, combined with the results from a previous study, which analyzed data from one beginner-level learner, a consolidated discussion has been provided.

It should be noted that this project is still in the process of accumulating data and analyses, and observations and discussions are still tentative. Nevertheless, one pattern is consistent in this project so far; if we compare the written tasks and the conversation tasks, brain activation is more significant for the conversation tasks than the written tasks. It is also suggested, based on the graph shapes of the conversation tasks, that brain activation may not be simply a matter of increased blood flow, but rather a degree of change.

The oxy-Hb data of the beginner-level learner generally seemed to correspond to brain activation. In contrast, the deoxy-Hb data seemed peculiar with regard to the correlation analysis; they exhibited strong negative correlations in many cases. Moreover, the trend charts for the intermediate-level learner showed that around Broca's area, the deoxy-Hb data increased more than the oxy-Hb data in some cases.

The study is still at the stage of seeking better ways to judge the similarity (or dissimilarity) between written tasks of various types and Japanese conversation tasks. In this regard, the use of correlation analysis has offered intriguing observations, which lead to a hypothesis about the developmental stages of the L2 system. Further, the current study and the previous study only considered the channels in which the absolute values of correlation coefficients were between 0.7 and 1.0. Expanding the lower range from 0.7 to 0.6 may provide a new insight for judging similarity (or dissimilarity).[13]

There is no doubt that brain activities during language tasks are complex. In order to understand the phenomena better, this study has suggested the importance of considering activation patterns (i.e., trends) and studying the nature of deoxy-Hb data. Due to an issue in the data size, correlation analysis has been applied to only two participants so far, and it is necessary to obtain more data and perform careful analyses.

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[13] This study employed the Guildford's (1973) threshold as in [$0.7 \leq | r | < 0.9$: strong correlation; $0.9 \leq | r |$: very strong correlation]. But Evans (1996) offers another categorization as [$0.6 \leq | r | < 0.8$: strong correlation; $0.8 \leq | r |$: very strong correlation].

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