Analysis of selective attention processing on experienced simultaneous interpreters using EEG phase synchronization

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Abstract— **This study analyzed the selective attention processing related to cognitive load on simultaneous interpretation (SI). We tested simultaneous interpreter's brain function using EEG signals and calculated inter-trial coherence (ITC) extracted by the 40-Hz auditory steady-state response (ASSR). In this experiment, we set two conditions as Japanese-English translation and Japanese shadowing cognition. We also compared two subject groups: S rank with more than 15 years of SI experience (n=7) and C rank with less than one year experience (n=15). As a result, the ITCs for S rank in interpreting conditions were more significantly increased than C rank in the shadowing conditions (ITC: $p<0.001$). Our results demonstrate that 40-Hz ASSR might be a good indicator of selective attention and cognitive load during SI in ecologically valid environmental conditions. It can also be used to detect attention and cognitive control dysfunction in ADHD or schizophrenia.**

I. INTRODUCTION

Simultaneous interpretation (SI) is an advanced cognitive task that performs multitasking and multi-modal processes. SI translates from their native language into a non-native language, therefore SI is a great difficult task that requires timely processing of listening, translating, and speaking. So, SI is called as an extreme case of multitasking [1]. Recently interests has been increased in the brain mechanisms that show how simultaneous interpreters overcome cognitive load [2], [3], [4].

Cohen's working memory model, which focuses on switching attention, is often used as a cognitive model to explain cognitive load during SI [2]. According to the model, each multitask is processed with a slight delay, and the interpreter must process each task one after another. Since the amount of information that can be focused on during SI is limited, exceeding these limits creates cognitive burden. In addition, small experiences with SI and different language structures make larger increase of the cognitive load [2], [3], [4].

In recent years, there has been a large number of publications directed to studying brain functions in SIs who have trained for managing multilingual language control. Many such studies using functional magnetic resonance imaging (fMRI) and electroencephalogram (EEG) have investigated the increased experience of interpretation and improved functional connectivity of the left dorsolateral prefrontal cortex streaming network [5], [6], [7], [8]. However, most studies control their experimental conditions by translating short sentences and short words without reflecting on the ongoing load faced by translators during actual simultaneous interpretations. It is also unclear how experienced simultaneous interpreter process the cognitive load and attention switching in the brain as described in Cohen's model.

A noteworthy study in translation [9] investigated the cognitive load associated with attention processing using EEG. This work focused on eliminating the process by which the human brain reduces attention to unrelated stimuli with increasing cognitive load and raised selective attention to the related stimuli. For unrelated stimuli, a task-independent probe stimulus (440 Hz, 52 ms pure sine tone) was used. By simultaneously presenting the translated speech and tone signals to the subject's ear, we analyzed the change in such event-related potential (ERP) amplitudes as N1 and P1 peaks that are induced by the tone signal to determine whether the filtering function was indicated. The N1 amplitude decreased, P1 increased with additional cognitive load, and the word familiarity remained low. However, they controlled the experimental conditions by editing the translated speech into a very short segmentation, which caused a departure from the actual SI translation situation.

The difficulty in measuring EEG during SI is the effect of environmental noise on EEG signals, such as mouth and hand movements, blinking, and interpreter's voice. To eliminate these effects, the experimental environment must be controlled, but the neural activity in a natural environment close to SI cannot be investigated. 40-Hz ASSR is a pulse response that has the same effect as quickly averaging many signals. This means that the ASSR signal must be extracted that appears at the same time as the translation without editing the original audio. Therefore, 40-Hz ASSR generally provides a robust response to environmental changes and creates an ecological experimental environment. Furthermore, recent studies have shown that when tasks of varying difficulty are aurally presented as 40-Hz ASSR, people can perform complex tasks in phase-locked responses in the 40-Hz ASSR [10].40-Hz ASSR is said to be associated with selective attention [10], [11] and also affects such attention and cognitive control dysfunctions as attention Deficit Hyperactivity Disorder (ADHD) and schizophrenia [5], [12], [13].

We conducted experiments to investigate the following two objectives:

1) To examine the relationship between cognitive load and the attention of simultaneous interpreters using 40-Hz

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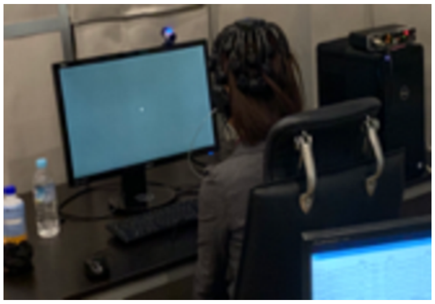

Fig. 1. EEG measurement during SI

ASSR.

2) To verify trained SI's brain functions in multilingual language control functions using 40-Hz ASSR.

II. Methods

A. Subjects

Professional, Japanese female interpreters (n = 22; ages ranged from 46 to 71, mean = 53.4, sd = 6.6) participated in our study. We ranked them as either experts (7 subjects with over 15 years of SI experience) and beginners (15 subjects with at least one year of SI experience). We called the expert group S and the beginner's group C. None had hearing-related problems or any history of neurological problems; all were right-handed. The Research Ethics Committee of our institution reviewed and approved this experiment. Written informed consent was obtained from them before the experiment.

B. Sound stimuli

We prepared eight topics from Japanese NHK radio news because it is Japan's most representative news channel. Most of the topics were political news and unlikely to elicit emotional responses [14]. We generated a 40-Hz pulse tone that elicits a 40-Hz ASSR response based on previous studies [15] (Fig. 2).

The synthetic speech sounds for interpretation were eight different 60-second length of Japanese radio news. We presented one-minute, synthetic speech, 40-Hz ASSR and Japanese radio news sound clips to their ears. The sound pressure was normalized with maximum amplitude. The pulse tone's sound pressure level was edited by a speech therapist to evaluate whether it could be heard adequately and whether it felt uncomfortable as 5% of the maximum amplitude of the news sounds. The 40-Hz pulse tones and news sounds were synthesized in stereo. We created audio files with open audio editing software called Audacity.

C. Task sequences

Our task was comprised of the following two conditions: translating from Japanese to English (TR condition) and shadowing (SW condition) as the participants heard the language (Fig. 3). We randomly presented eight bits of news under the two conditions. We presented the stimuli by presentation software provided by Neurobehavioral Systems

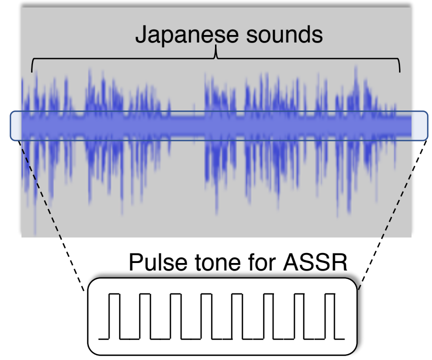

Fig. 2. Synthetic speech sounds of 40-Hz ASSR and Japanese radio news

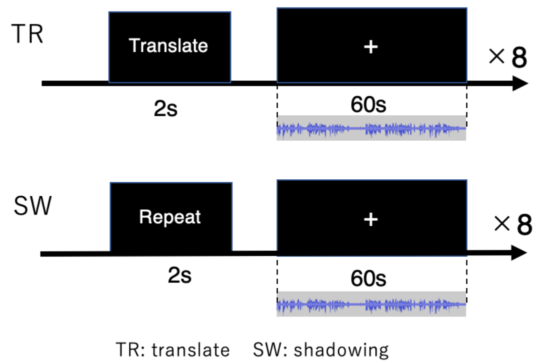

Fig. 3. Task sequences between tasks. TR: translation, SW: shadowing

(Version 18.0, Neurobehavioral Systems, Inc., Berkeley, CA, www.neurobs.com).

D. Subjective evaluation

After the EEG experiment, subjects were instructed to answer the subjective evaluation sheet for the eight topics and five questions. The following are the question contents: Q1: achievement for interpretation, Q2: topic field, Q3: voice speed, Q4: a comfortable voice for listening, and Q5: Overall interpretation difficulty. The questions were evaluated on five scales:, where scale 1 was the most easy and scale 5 was the most difficult. After answering all five questions, our participants were encouraged to add their own comments.

E. EEG data acquisition and prepossessing

The EEG signals were recorded with a Cognionics Quick-30 Dry EEG Headset with 29 electrodes (excluding one for the reference channel) [1]. The recorded signals were band-pass filtered from 1 to 50 Hz at a sampling rate of 500. The EEG signals were referenced by subtracting the average signal of A1 and A2. The ground electrode was placed in the center between Fp1 and Fp2. All the EEG signals were processed using MATLAB (Math Works, Natick, MA, USA).

1) Inter-trial coherence (ITC): To quantify the cognitive load using EEG signals, we extracted the phases at 40-Hz and calculated ITC based on previous research [16]. We divided the continuous EEG data into trials of three seconds and shifted them by one second [17]. We performed a Fourier transform at 40 Hz for each channel and calculated the ITC based on the following equation:

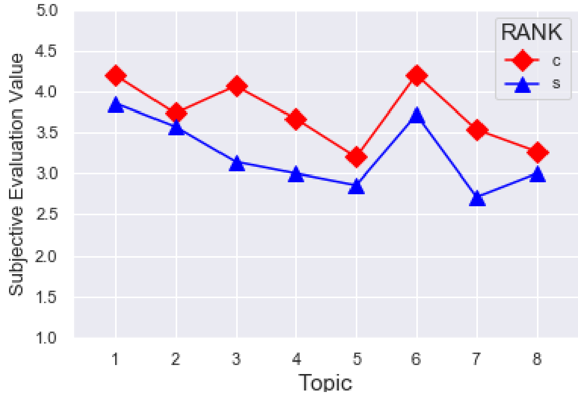

Fig. 4. Interaction plot between RANK and TOPIC for subjective evaluation value on Question 1

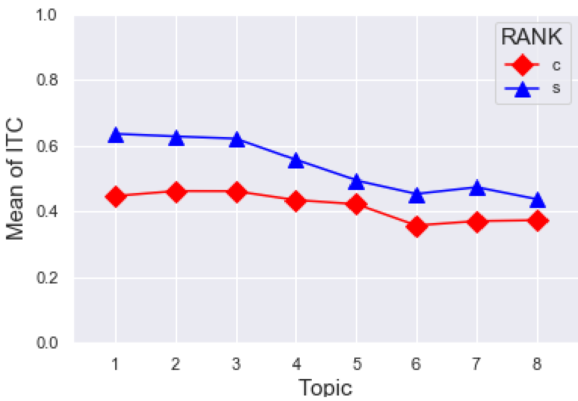

Fig. 5. Interaction plot between TOPIC and RANK on TR condition

$$ITC[ch] = |\frac{\sum_{k=1}^{K} exp(j\theta_k^f[ch])}{K}|,$$

where f is a frequency, ch is the channel number, θ_k^f is the phases of frequency f and electrode ch, k is a trial number, and K is the number of trials. Since the cognitive control function of SI is involved in the frontal lobe, this study focused on the frontal lobe channels. The ITCs were calculated for each news bit over the three frontal electrodes ('F3', 'Fz', and 'F4') and averaged over the electrodes [16]. We selected the frontal lobe electrode because many previous studies concluded that the multilingual processing functions of trained SIs are localized in the frontal lobe.

2) Statistical analysis: To verify the difficulty of the ranks during SI for subjective evaluation, we performed two-factor factorial ANOVAs with topics (8 NHK news) and experiment ranks (C and S). Since the contents of the five questions were not related, they were considered independent variables, and ANOVAs were performed for each question. For the ITC values, we performed two-factor factorial ANOVAs with rank (C and S) and task (TR and SW) to analyze the rank and task effects.

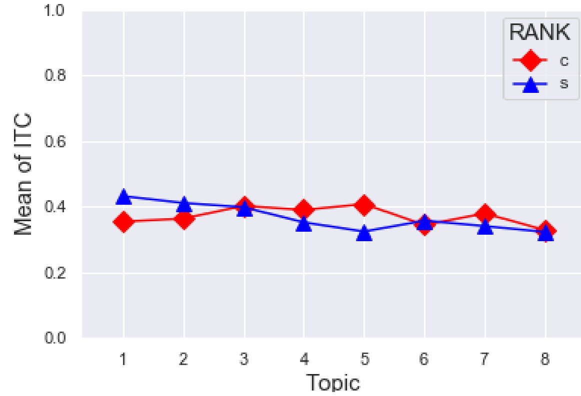

Fig. 6. Interaction plot between TOPIC and RANK on SW condition

III. RESULTS

A. Subjective evaluation

We performed two-factor factorial ANOVAs for all five questions. In Q1 and Q2, the difficulty for the C rank significantly exceeded the S rank. The only main effects that appeared with the rank were Q3 ($F_{1,7}$=13.7, $p<0.001$) and Q4 ($F_{1,27}$=22.5, $p<0.001$). In addition, the only topic that showed the main effect was on Q5 ($F_{7,23}$=4.3, $p<0.001$). We found a main effect in both the rank and topic for Q1 (rank; $F_{1.9}$=12.7, $p<0.001$, topic: $F_{7.22}$=4.3, $p<0.001$) and Q2 (rank:$F_{1.4}$=6.4, $p<0.001$, topic: $F_{7.9}$=2.1, $p<0.05$). On the other hand, we identified no interactions between the rank and topic for all the questions (Fig. 4).

B. ITC

When the two-factor ANOVAs were applied to the ITC values on the frontal cite electrodes, we identified a statistically significant influence of the rank for the TR condition ($F_{1,0.5}$ = 12.1, $p<0.001$)(Fig. 5), although the rank for the SW condition showed no significance ($F_{1,0.00}$ = 0.02, p=0.8)(Fig. 6). The main effects of the topic on TR and SW did not show any significance (TR: $F_{7,0.4}$ = 1.5, p = 0.16; SW: $F_{7,0.08}$=0.4, p=0.8), and no interactions were detected between the rank and topic factors for each condition (TR: $F_{7,0.06}$ = 0.2, p = 0.9; SW: $F_{7,0.08}$=0.4, p=0.8). In addition, for the task (TR and SW) and rank (S and C) factors, two-factor factorial ANOVAs showed a statistical difference in rank ($F_{1,0.2}$ = 7.5, $p<0.001$) and task ($F_{1,0.6}$ =18.1, $p<0.001$) as well as a significant interaction between rank and task ($F_{1,0.3}$ = 8.6, $p<0.01$) (Fig. 7).

IV. DISCUSSION

A. The subjective evaluation value for S and C rank interpreters

Regarding the difficulty of translating for the subjective evaluations, in 4 of the 5 subjective evaluation questions, the main effect of evaluation value between S and C was significant, and the value of C was significantly higher than the S of it. In almost all the questions, interpreting for the C seemed more difficult than the S (Fig. 4).

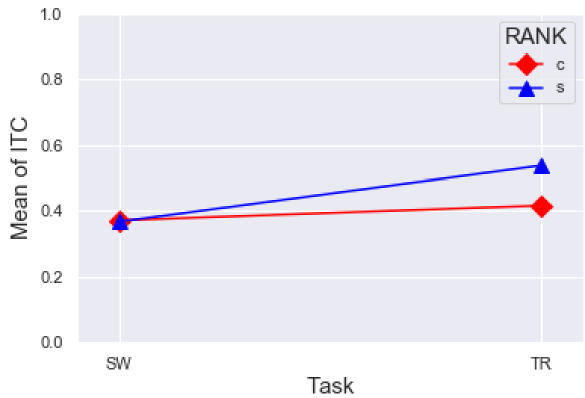

Fig. 7. Interaction plot between TASK and RANK

B. *Changes in selective attention processing of translation and shadowing conditions*

Considering the phase-lock response on an ITC value to attention processing, the ITC of the S rank was significantly higher than the C rank under the TR condition (Fig. 5). But the SW between the C and S ranks showed no difference among the conditions (Fig. 6). Regarding the task, although the difference in the ITC values between the ranks (especially in the S rank) was larger in the TR condition than in the SW condition, we observed no difference under the SW condition (Fig. 7). These results clearly show that the S-rank phase synchronization increased during the conversions. Earlier studies showed that 40-ASSR is associated with selective attention [16], [10], [18], [1]. The TR and SW tasks in our study reflect differences in selective attention focused on different tasks, and when focusing on the same voice as NHK news, TR requires increased attention to the translation. These responses suggest that 40-ASSR is associated with selective attention, and for TR and SW, the subjects reflect differences in the attention targets because they were listening to the same news topic and differences in selective attention. This may indicate an increase in the S-rank selective attention while interpreting. The trained SI's brain function might have increased the multilingual language control in the prefrontal cortex. This result supports many previous studies [5], [6], [7], [8].

V. Conclusions

We extracted phase-synchronous responses during simultaneous interpretation using 40-Hz ASSR, detected the multilingual processing control network of the frontal lobe in trained interpreters, and supported previous studies. We showed that ITC can be a measure of cognitive load and selective attention in SI. In the future, we will verify cognitive load and attention using such a behavior as speech interpretation and conduct research that will lead to the diagnosis of the bio-markers of such attention diseases as ADHD and schizophrenia.

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