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Near-Infrared Spectroscopic Measurements of Attention to Degraded Speeches

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Abstract: *The purpose of this research is to discuss the effect of distractors on human attention function by altering the extreme value of the sound waveform to the phase direction in order to intentionally create sounds that are unclear (deterioration of sound). A listening test (auditory attention examination) was given to 10 subjects who listened to sounds for which the extreme value of the sound waveform was altered, and the accuracy rate was calculated. Furthermore, to objectively observe the activation state of the frontal lobe while listening to the altered sounds, NIRS (Near Infrared Spectroscopy) was used to measure the change in oxy-Hb. Increase in oxy-Hb in the frontal lobe was confirmed when subjects were exposed to deteriorated sounds. It was observed that the existence of sound distratcors enhanced the activation of the auditory attention function (the frontal lobe), and by changing the quality of the distractors, it was implied that degree of activation of the auditory attention function may change.*

Keywords *Attention function, Distractor, Phase, NIRS*

1. Introduction

The sound information enters from the auditory organ and reaches to the cerebral cortex. It is widely known that the temporal lobe plays an important role in the auditory perception [1]. Also in neuropsychology, it is said that auditory cognitive disorder develops when the temporal lobe is damaged [2, 3]. However, it is also reported that various cognitive disorders develop when the attention function of the higher brain function is damaged [4, 5].

The attention function is the basis of the higher brain functions [6], and problems in the attention function more or less cause deterioration of all cognitive functions. Thus, recognition of sound may be affected by the attention function. It is thought that the attention function is controlled by the frontal lobe [7, 8], and attention disorder is frequently observed when the frontal lobe is damaged [9]. Even for the cognitive function of a normal adult, if any distractors are present, the effective utilization of the attention function will be interrupted, and it is expected that normal cognitive activities will be limited.

The purpose of this research is to discuss the effect of distractors on human attention function by altering the extreme value of the sound waveform to the phase direction in order to intentionally create sounds that are unclear. In this research, a listening test (auditory attention examination) was given to 10 subjects who listened to sounds for which the extreme value of the sound waveform was altered, and the accuracy rate was calculated. Furthermore, to objectively observe the activation state of the frontal lobe while the subject was listening to the altered sounds, NIRS (Near Infrared Spectroscopy), a brain function imaging technique, was used to measure the change in oxy-Hb.

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2. Attention function in higher brain function

The attention function in higher brain function refers to the process of concentrating on, sustaining, and transferring consciousness against adequate external and internal stimuli during wakefulness. The attention function is intimately related to other higher brain functions such as recognition, memory and language. The attention function is further divided into 4 types: sustained attention, selective attention, alternating attention and divided attention [10, 11]. Because attention disorder affects all higher brain functions, in order for a specific cognitive function to function properly, the effective utilization of attention is required [12].

3. Clinical Assessment for Attention: CAT.

CAT is the standardized neuropsychological examination for attention disorder patients in Japan [13]. CAT consists of several sub-tests.

“Span” assesses the range or strength of simple attention and consists of Digit Span and Tapping Span. “Cancellation and Detection Test” assesses the selective attention, of which the Visual Cancellation Task examines relatively simple auditory attention by selecting 3 modalities: figures, numbers, and *kana* (Japanese syllables); and the Auditory Attention Task examines auditory selective attention. “Symbol Digit Modalities Test”, “Memory Updating Test”, “Paced Auditory Serial Test” and “Position Stroop Test” are highly related to alternating attention and divided attention. Also, regarding cognitive psychology, the central executive of the working memory is reflected. “Continuous Performance Test” is capable of assessing abilities regarding sustained attention.

The result of the examination is evaluated according to the number of correct answers and accuracy rate. The higher the score is, the higher the ability of the subject is, and the attention function can be considered as good.

4. Near-infrared spectroscopy: NIRS

NIRS uses near infrared light that penetrates through human tissue and noninvasively measures Hb oxygen metabolic change in a living organism [14]. The light-emitting source and the corresponding detector are positioned on the head according to the International 10-20 System [15]. The near infrared light is emitted from the light source and is weakened as it is scattered and absorbed by the brain tissue, while some fraction of the injected light passes through and is detected by the detector. By measuring the change in the strength of detected light, the change in the concentration of oxy-Hb and deoxy-Hb on the brain surface can be calculated. The change in Hb concentration is calculated based on the Beer-Lambert law. In a medium that scatters light greatly such as living tissues, the optical path length becomes longer than the actual thickness of the medium because the light keeps scattering. Therefore, by using the Beer-Lambert law, the change in the concentration of oxy-Hb and deoxy-Hb on the brain surface can be calculated. Because NIRS has very high time resolution of 0.1 second while its spatial resolution is about 3 cm, it is suited for observing higher brain functions in widespread areas such as the association area of the cerebral cortex [16, 17].

5. Method

5.1 Subjects

Ten right-handed 20-year-old subjects (male: 10, female: 10) with no background of hearing disorders or cerebrovascular disease were selected. In accordance with the Declaration of Helsinki, the purpose of this research was explained to the subjects, and they all agreed.

5.2 Auditory attention function examination and stimulus sound

The auditory attention function examination conforms to Auditory Detection Task (ADT) set 1 in CAT. ADT is an examination in which among 5 types of stimulus sounds provided on a CD, the subject is to tap on the target sound /to/. The stimulus sounds other than the target sound are phonologically distant /go/ and its related sounds /do/, /po/, and /ko/. These 5 types of sounds, /to/, /go/, /do/, /po/, and /ko/, are played back in one-second intervals and randomly repeated. The duration of the examination is 60 seconds, and the target sound of /to/

appears randomly 10 times.
In terms of the stimulus sounds, the sounds in ADT set 1 were regarded as the standard stimulus sounds (SS). In addition to SS, variations of SS were created by altering the extreme value of the sound waveform by ±4% to ±14% to the phase direction, so that a total of 12 sound variations including SS were used (SS, phase variance ±4%, ±5%, ±6%, ±7%, ±8%, ±9%, ±10%, ±11%, ±12%, ±13%, and ±14%). Extreme operation to the phase direction is the same as the operation in extreme Yoshida[18].

The greater the phase variance of the extreme value of the sound waveform, the less clear the degraded sound becomes, and this becomes a factor preventing subjects from hearing accurately [19, 20].

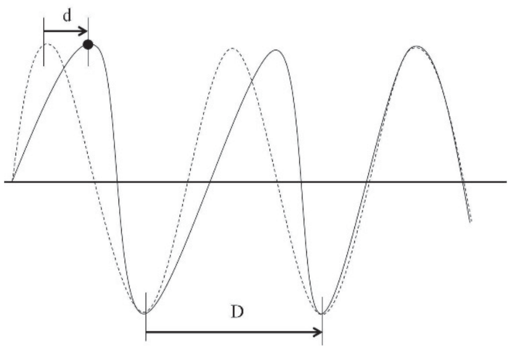
The result was evaluated by calculating the accuracy rate of each of 12 sound variations. The statistical analysis of the change in the accuracy rate with respect to the level of the phase variance was performed (ANOVA, significance level of 0.01). Also, subjects took adequate breaks between examinations.

5.3 Functional neuroimaging

Using NIRS, the state of the frontal lobe activation was observed objectively and quantitatively as subjects listened to sounds altered acoustically. The stimulus sounds used for NIRS measurement were SS, the sound in which the sound waveform of SS was altered by ±9% to the phase direction (Deviant-1 Stimulus Sound: D1), and the sound altered in the same manner by ±14% (Deviant-2 Stimulus Sound: D2).

During measurement, the subjects wore a 37-channel probe set on the head so that it covered the frontal lobe according to the international 10-20 system (for example; Fig. 2). The subject sat on an armchair in a quiet room and listened to the stimulus sounds (60dBSPL) that came from a speaker placed 1m away from the subject.

It was so designed that the sequence of Rest (no sound: 15 seconds) – Task (stimulus sounds: 60 seconds) – Rest (no sound: 15 seconds) was set to be 1 block, and it was repeated 3 times. The simple average of the 3 oxy-Hb values was calculated, and the change in oxy-Hb level for each rest-task stimulus sound sequence was compared and observed (t-test, significance level 0.01). The NIRS used in this research was LABNIRS manufactured by Shimadzu Corporation (3 wavelength: 780±5nm, 805±5nm, 830±5nm, Output: 0.39W).



$$\text{phase error: } P[\%] = \frac{100}{N}\Sigma\frac{d}{D}$$

Fig. 1. Extreme manipulation of waveforme [18]
The black circle is the extreme value after the movement. The solid line is the waveform that has been modified in accordance with the movement of the extreme value. Dashed line is the original waveform.

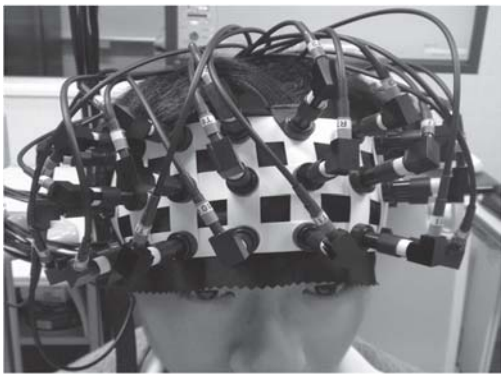


Fig. 2. Installation place and Channel arrangement of probe

6. Results

6.1 Auditory Attention Examination

The average accuracy rates of SS and each of its phase variances ±4%, ±5%, ±6%, ±7%, ±8%, ±9%,

±10%, ±11%, ±12%, ±13%, ±14% were 99.1%, 91.8%, 94.8%, 89.4%, 83.5%, 85.0%, 78.0%, 59.3%, 58.6%, 57.3%, 47.1%, 45.2% respectively. As the variance of the extreme value became greater, the accuracy rate gradually became lower; however, a significant decrease ($p<0.01$) was confirmed between ±9% and ±10% (for example; Fig. 3).

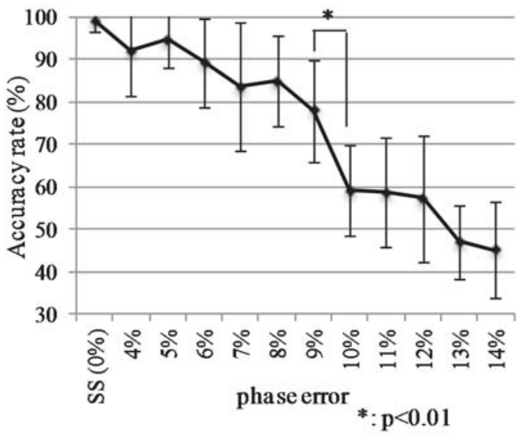
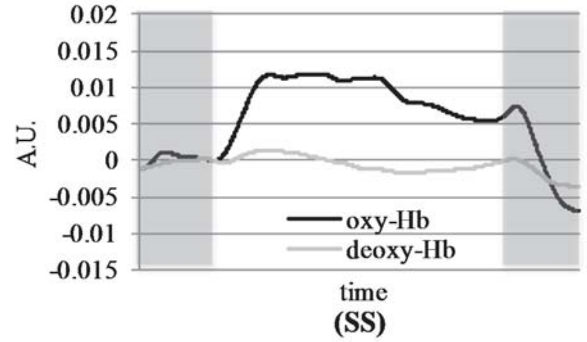


Fig. 3 Accuracy rate of auditory attention examination for each stimulus sound

6.2 Measuring oxy-Hb

Fig. 4 shows the chronological change in oxy-Hb and deoxy-Hb for SS, D1 and D2.

Fig. 5 shows the average oxy-Hb between the rest and the task for each stimulus sound. For all stimulus sounds, a significant increase in oxy-Hb ($p<0.01$) was confirmed during the task compared to the rest.



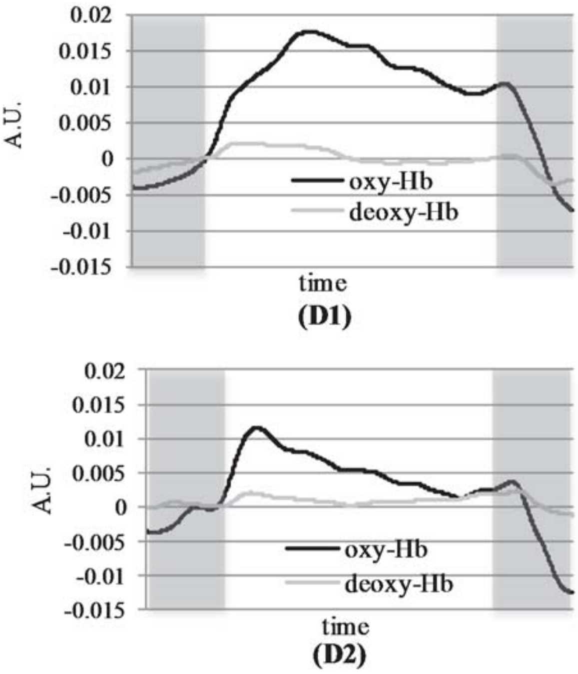


Fig. 4. Chronological change in Hb for each stimulus sound (Gray areas indicate rest)

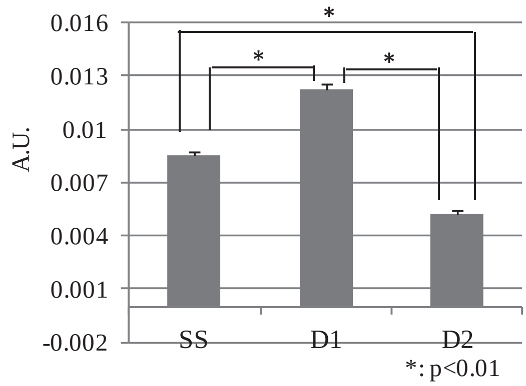


Fig. 5 The average of oxy-Hb at the task about each stimulus sound

7. Discussion

In this research, the extreme value of the standard waveform was altered to the phase direction making the sound unclear in order to perform the auditory attention examination. The greater the phase variance, the lower the accuracy rate gradually became. The sound deterioration is said to start when the phase variance is between 4% and 9% [21], and as the sound deteriorates, the accuracy rate decreased in this research as well. This was caused by the malfunction of the auditory cognitive function as a result of the masking effect. Also, when the phase variance exceeded 9%, the accuracy rate decreased significantly. The phase is generally defined and used as the difference in the time that the sound wave arrives at each ear from the same sound source (ITD: Interaural Time Difference), and it has been discussed as a part of the auditory perception to localize the sound source. Among various sound localization perceptions, the clue to estimate the horizontal direction of the sound source is said to be in the ITD that consists of frequencies 1500Hz or less [22]. The pure sound is perceived from about 50μs [18], and when the phase variance reaches 7.5%, the subject notices that the sound source has changed its position. Thus, when the extreme value of the waveform is altered to the phase direction by 7% or more, the waveform is altered to a degree that is impossible to happen in reality [18]. This will cause a crisis in the brain while processing auditory information.

However, in this research, the accuracy rate exceeded 80% when the phase variance was 7%, 8% and 9%, which implies that the critical crisis is not taking place while processing auditory information. Further, when the phase variance exceeded 10%, the accuracy rate decreased suddenly and when the phase variance was 14%, the accuracy rate fell below 50%. It is thought that the attention function plays an important role when we recognize and process information gathered from the external environment. Also, the attention function is considered to be the basis for all of the higher brain functions including the cognitive function [6]. According to the results obtained in this research, we can hypothesize that the attention function is supplementing the auditory perception until the distractor reaches a certain level. Thus, in order to objectively quantify the activation condition of the frontal lobe that controls the attention function, we thought that the brain function imaging would be effective.

Among brain function imaging techniques, PET(Positron Emission Tomography), fMRI(functional Magnetic Resonance Imaging), MEG(Magnetoencephalography), EEG(Electroencephalography), and NIRS(Near Infrared Spectroscopy) are often used. However, PET, fMRI, MEG and EEG are mainly used while subjects are in a relaxed or non-active state due to limitations on the structure of the device and the measuring condition. Because NIRS is quiet and more flexible, it is becoming the non-destructive brain function measuring device of choice for brain function researches and activities that use "sounds". In this research, NIRS was chosen because it is quiet by design, and we proceeded to discuss the auditory attention function using sounds.

D1 had the largest change in oxy-Hb concentration, then SS, and D2 had the least change. The change in oxy-Hb concentration indicates increased blood flows to the areas of activation [23]. Thus, it is suggested that D1, with sounds moderately unclear, activated the frontal lobe the most. ADT used this time is an examination method that is most sensitive to selective attention. Further, by altering the extreme value of the sound waveform, the sound deteriorated, acting as interference or a distractor when selecting the target sound. The function to control the interfering stimulus is included in Supervisory Attention System (SAS), as the central attention function, and the frontal lobe plays a very important role for SAS [7, 8]. In this research, sound deterioration due to phase variance is considered as interference or a distractor, and the increased blood flow to the frontal lobe was identified; therefore, it is suggested that the frontal lobe plays an important role for SAS function as suggested in previous researches. However, D2, which had the stronger phase variance, resulted in the least increase in oxy-Hb. Further, considering that the accuracy rate fell below the chance level, it is possible that the sound information was damaged critically. This implies that the sound emitted in a one-second interval during the examination may have been regarded as a noise or a cluster of meaningless sounds. This is because the distractor was too strong and selecting the target sound was made too difficult, so the increase in oxy-Hb in the frontal lobe was limited.

As described above, it was observed that the distractor to sounds enhances the activation of the auditory attention function (the frontal lobe); however, it was suggested that the change in the quality of the distractor may affect the degree of activation of the auditory attention function. But, in this research, we have not investigated the Wernicke's filed relations, influences and subject's motivations at the task. We would like to consider the auditory attention function in detail from now on.

8. Conclusion

In this research, when performing the auditory attention function examination using sounds altered acoustically, NIRS was used to quantitatively observe the activation of the auditory attention function. Also, it was suggested that the interference or a distractor during cognitive tasks enhances the activation of the attention function. The report on the improvement of the memory and the performance of language tasks was made as well [24-27], and it is expected to be applied to rehabilitation in the future.

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