Effect of emotionally toned Malay language sounds on the brain: a NIRS analysis

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Abstract— Speech recognition features such as emotion have always been involved in human communication. With the recent developments in the communication methods, researchers have investigated artificial and emotional intelligence to improve communication. This has led to the emergence of affective computing, which deals with processing information pertaining to human emotions. This study aims to determine positive influence of language sounds containing emotion on brain function for improved communication. Twenty-seven college-age Japanese subjects with no prior exposure to the Malay language listened to emotionally toned and emotionally neutral sounds in the Malay language. Their brain activities were measured using near-infrared spectroscopy (NIRS) as they listened to the sounds. A comparison between different NIRS signals revealed that emotionally toned language sounds had a greater impact on brain areas associated with attention and emotion. On the contrary, emotionally neutral Malay sounds affected brain areas involved in working memory and language processing. These results suggest that emotionally-charged sounds initiate listeners' attention and emotion recognition even when the listeners do not understand the language. The ability to interpret emotions presents challenges in computer systems and robotics; therefore, we hope that our results can be used for the development of computational models of emotion for autonomous robot research in the field of communication.

Keywords— Malay language, NIRS, Brain activity, Language area.

I. INTRODUCTION

Speech recognition systems are greatly involved in human communication, and they experience challenges when unfamiliar languages are encountered. To achieve mutual understanding, emotion has been shown to be an important feature in human communication systems [1]. It has also been demonstrated that gesture, voice, expression, and context increase the likelihood of accurate interpretation in communications [2]. With the recent growth in technology, the mass adoption of computing devices has transformed the way people communicate in modern society [3]. Computer-based communication has become so common that it is difficult to imagine the world without computers and networks [4]. Additionally, machines that express emotions are no longer science fiction [1], and they are studied in the field of affective computing [5]. Affective computing involves emotional information that machines interpret, express, manage, and respond with to the users [6].

As a result of the increased use of features such as voice and camera inputs, human–robot communication has attracted a significant amount of attention. Consequently, it is necessary for machines to be able to understand human language. To this end, the emotions and expressions of robots should be understandable and interpretable not only by humans but also by machines themselves. Therefore, human thought processes must be integrated in a computerized model as a target for the development of cognitive computing. However, we cannot yet expect robots to respond timely enough in a sensible manner because of the lack of system robustness, especially in recovering all the information through the sensors [6].

This study aims to determine whether language sounds that contain emotion influence brain function positively for improved communication. The study results were expected to contribute to the research of affective computing in terms of communication between robots and humans. Herein, we used the Malay language, an entirely new language sound for the subjects, to separate emotion from sentence semantics. In this way, emotional comprehension could be isolated from semantic comprehension.

Many studies have investigated artificial and emotional intelligence to improve methods of communication, including robot–robot communication [7]-[9]. By understanding human communication systems, it is possible to apply them to robot communication systems. To understand brain function mechanisms, we conducted an experiment using near-infrared spectroscopy (NIRS) system. NIRS is used to measure hemoglobin (Hb) concentration changes in real time on the brain surface using diffuse optical techniques. The concentration of Hb is observed through the use of light scattering and tissue absorption. In the range of 650–950 nm of NIR light, skin tissue and bone are mostly transparent, whereas oxygenated Hb (oxy-Hb) and deoxygenated Hb (deoxy-Hb) are strong absorbers [10]. The differences in light absorption thus enable the measurement of relative changes in Hb concentration [11].

Recently, additional brain imaging techniques, such as electroencephalography (EEG) and functional magnetic resonance imaging (fMRI), among others, have been used for communication research [12]. However, with some techniques, it is difficult to measure region-specific brain activity due to the limited spatial resolution, as is the case for EEG. On the contrary, fMRI can be used to achieve high spatial resolution but at the expense of poor temporal resolution and restricted subject mobility [13]-[14]. As a result, NIRS has been proposed as an alternative, as it has a spatial and temporal resolution between that of EEG and fMRI [14]. We used NIRS in this study because it is non-invasive and less costly than other techniques. Although it repeatedly uses infrared rays in taking measurements, it is unknown to have any adverse effects on the body, even in infants. Additionally, due to its mobility, it can be used not only for natural postures such as sitting and standing but also during actual utterance and movement [15]. Furthermore, NIRS can be used to detect localized affect-related brain activity, such as the prefrontal cortex presenting functional coupling in response to emotionally-charged tasks [14].

II. METHODOLOGY

Herein, 27 college-age Japanese subjects listened to emotionally toned and emotionally neutral sentences in the Malay language. We used the Malay language because it is a new language sound for the subjects. We recorded five Malay sentences to compare emotionally charged and emotionally neutral language sounds. Each sentence was repeated twice, with and without emotional intonation. Five emotions were selected, happiness, surprise, sadness, anger, and fear. We used sentences without obvious emotional connotations, such as "saya nak pergi makan (I'm going to eat)," to examine the influence of emotional intonation instead of semantic content. To identify which parts of the subjects' brains were activated while listening to the sentences, relative changes in the blood Hb concentrations in their brains were measured using a NIRS system. Prior to the NIRS measurement experiment, a verification test was conducted on the Malay sentences to confirm that each sentence conveyed the intended emotion to Japanese individuals unfamiliar with Malay language sounds.

A. Verification test

To determine whether the Malay sentences successfully conveyed their intended emotions, 44 Japanese university students (different from the subjects in the NIRS experiment) participated in an emotion recognition test. They listened to five Malay sentences and indicated the emotion they felt by circling one of the five words on a questionnaire. The questions and words were identical for all emotional Malay sounds, and all the instructions and questions were written in Japanese. The questions and five choices are shown in Fig. 1 in their English translations. The test was conducted to verify that the recording of the Malay sentences was suitable for the NIRS experiment.

When listening to this sentence, which emotion
represents speaker's real feeling?

A. Anger B. Surprise C. Sadness
D. Fear E. Happiness

Fig. 1. English translation of the question and five answer choices in the questionnaire.

The average percentage of correct answers for each emotionally toned Malay sentence was calculated, as presented in Figure 2. The majority of participants correctly identified each emotion; as a result, we deemed the Malay sentences with five emotions suitable for experiments using NIRS to measure brain activity during emotional language sound processing.

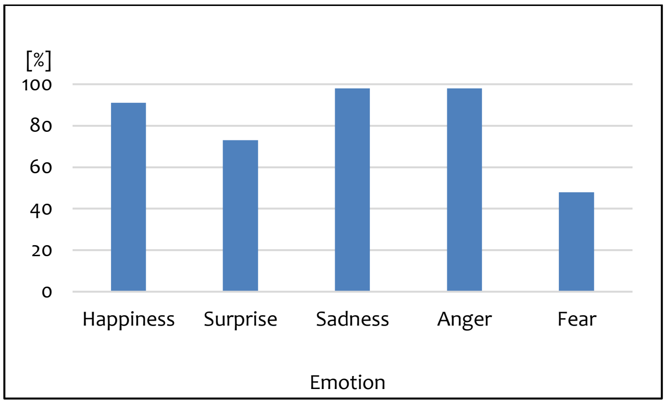


Fig. 2. Average percentage of correct answers.

B. Instrumentation

We used a NIRS system (Hitachi Medical Corporation ETG 4000, Japan) that measures and records the changes in the cerebral blood volume of oxy-Hb, deoxy-Hb, and total Hb in the brain every 0.1 s. Brain area activation can be detected by the increments of the values of the oxy-Hb changes. A single 3 × 11 measurement patch was used in this experiment, and 17 irradiation and 16 detection probes were alternated for a total of 33 probes in the patch. The distances between the irradiation and detection probes (measurement area) are called channels and are 30 mm apart. Fifty-two channels were used in this experiment to observe the brain activity of each subject. We used 52 channels simultaneously to measure approximately half of the brain from the frontal lobe through its left side. With the ETG 4000 system, the relative oxy-Hb and deoxy-Hb concentration changes and the total Hb concentration changes of the blood volume can be detected based on the brain state after the start of the measurements. We not only recorded Hb concentration changes during the measurements but also observed the measurement results in real time. The results can be visualized as 2D or 3D topographic images of activated brain areas.

C. *NIRS experiment*

To assess the activity in the language areas of the brain, the channels were positioned to cover the left hemisphere of the brain, including part of the prefrontal cortex and Broca's and Wernicke's areas. Figure 3 shows the positions of the NIRS probes on a subject's head. The positions of the probes on the patch and the NIRS measurement areas are presented in Fig. 4.

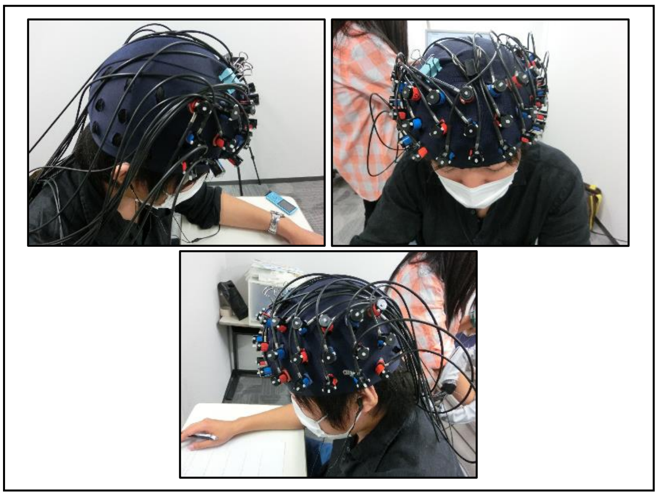


Fig. 3. NIRS probe position on a subject's head.

Twenty-seven healthy right-handed Japanese university students (23 male and 4 female) between 19 and 26 years of age participated in the experiment. Their first language was Japanese, and none had any prior knowledge of or experience with the Malay language. Since the left hemisphere of the brain is dominant for language processing in right-handed people [16]-[17], this experiment was conducted with right-handed subjects. Only the left hemisphere of the brain was covered with channels, including part of the frontal region of the prefrontal cortex and the language areas (Broca's and Wernicke's areas).

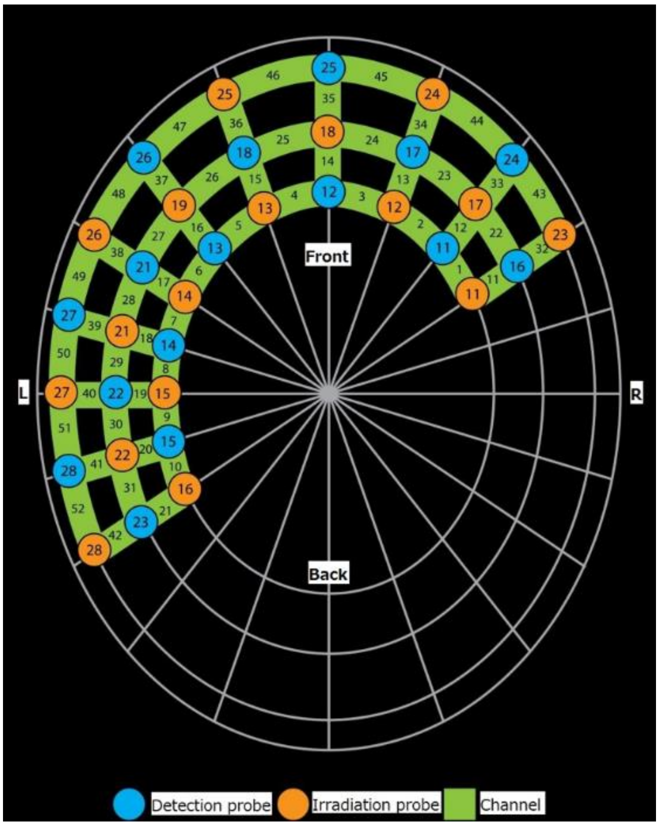


Fig. 4. Placement of NIRS probes.

The subjects in this experiment heard five sentences in Malay with five different emotions: happiness, surprise, sadness, anger, and fear. The subjects then answered a questionnaire after listening to both the emotionally toned and emotionally neutral sentence to indicate which emotion they felt the sentence expressed. The questionnaire format was identical to that in the verification test. The brain activation of each subject was measured throughout the experiment by the NIRS system. The experiment was recorded with a video camera to synchronize the timing of the subject's listening with the timing of the NIRS signals. For each subject, we measured the Hb concentrations from the moment the sentence began to the moment it ended. Figure 5 presents a flowchart of the experimental process.

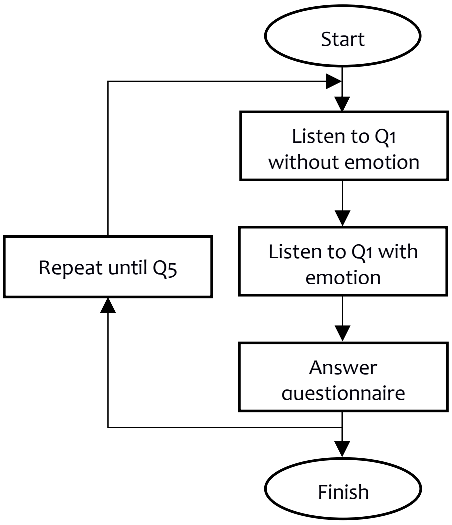


Fig. 5. Flowchart of experiment.

III. RESULTS AND DISCUSSION

We analyzed the NIRS signals in relation to brain area function. For all 27 subjects, the total Hb concentration changes were measured every 0.1 s with the NIRS system and were averaged for both emotionally toned and emotionally neutral sentences. The measured oxy-Hb data from all subjects was averaged for each channel. Table 1 presents the average NIRS signal values for each emotion for channels 6, 27, 37, and 48, which roughly correspond to the language areas of the brain.

TABLE I

AVERAGE NIRS SIGNAL VALUES FOR MALAY SENTENCES OBTAINED FROM CHANNELS (CH) 6, 27, 37, AND 48 (ROUGHLY CORRESPONDING TO THE LANGUAGE AREAS OF THE BRAIN). FOR COMPARING EMOTIONALLY TONED AND EMOTIONALLY NEUTRAL SENTENCES, RED NUMBERS INDICATE HIGHER VALUES FOR EACH CHANNEL. HIGHER VALUES FOR EMOTIONALLY NEUTRAL SENTENCES ARE UNDERLINED.

Ch # & No/With emotion		Happiness	Surprise	Sadness	Anger	Fear
6	No	−0.079	−0.075	−0.066	−0.114	−0.190
	With	−0.091	−0.083	−0.033	−0.116	0.034
27	No	−0.093	−0.063	−0.085	−0.107	−0.052
	With	−0.104	−0.071	−0.091	−0.041	−0.132
37	No	0.002	0.055	0.028	−0.003	0.011
	With	0.001	0.021	0.022	0.030	−0.142
48	No	0.099	0.102	−0.091	0.142	0.071
	With	0.090	0.073	0.137	0.191	−0.152

Table 1 demonstrates that for more than three emotional language sounds, the average Hb concentration changes for the channels that covered language areas were higher for emotionally neutral sentences than for emotionally toned sentences (underlined in Table 1). We analyzed the NIRS signals obtained from these channels using t-tests. A paired t-test was performed on each sentence between the signal values for the emotionally toned and emotionally neutral sentences ($\alpha = 0.05$). The t-test result reveals a significant difference for channels 37 and 48 between emotionally neutral sentences and sentences with the emotion of fear. Table 2 presents the t-test results.

TABLE II

T-TEST RESULTS FOR HB CONCENTRATION CHANGES FOR CHANNELS 37 AND 48.

Channel #	Emotions	Pearson correlation	t stat	P(T<=t)
37	Fear	0.9413	2.6072	0.0149
48	Fear	0.9432	3.4697	0.0018

The Hb concentration changes for both channels 37 and 48 were higher when subjects listened to emotionally neutral sentences in comparison to emotionally toned sentences. For channel 48, the results demonstrate a significant difference between sentences with fear and emotionally neutral sentences ($p < 0.01$). In addition, other channels not corresponding to language areas were also activated when the subjects listened to both emotionally toned and emotionally neutral sentences. The averaged NIRS signal values from these channels are summarized in Table 3.

TABLE III

AVERAGE NIRS SIGNAL VALUES FOR MALAY SENTENCES OBTAINED FROM CHANNELS 5, 11, 25, 34, 36, 44, AND 47. RED NUMBERS INDICATE HIGHER VALUES FOR EACH CHANNEL BETWEEN EMOTIONALLY TONED AND EMOTIONALLY NEUTRAL SENTENCES. HIGHER VALUES FOR EMOTIONALLY NEUTRAL SENTENCES ARE UNDERLINED.

Ch # & No/With emotion		Happiness	Surprise	Sadness	Anger	Fear
5	No	-0.0835	-0.0801	-0.0489	-0.0612	-0.0321
	With	-0.0972	-0.0904	-0.081	-0.0678	-0.1025
11	No	-0.3614	-0.3255	-0.2248	-0.2301	-0.2595
	With	-0.3645	-0.3503	-0.265	-0.2335	-0.1289
25	No	0.0197	0.0732	0.1234	0.1034	0.0292
	With	0.0004	0.0632	0.1076	0.0925	0.0847
34	No	0.0727	0.1314	0.1871	0.1425	-0.0049
	With	0.0903	0.1413	0.1558	0.1644	0.1204
36	No	0.0711	0.1098	0.106	0.0965	-0.1174
	With	0.0528	0.1169	0.1056	0.0968	0.083
44	No	-0.0572	-0.0427	0.0092	-0.0175	-0.1275
	With	-0.043	-0.0037	0.0006	0.0213	-0.0207
47	No	-0.0746	-0.043	-0.0375	-0.0503	-0.235
	With	-0.0562	-0.0468	-0.0449	-0.0607	-0.04

As seen in Table 3, the average Hb concentration changes for channels 5, 11, 25, and 47 are higher for emotionally toned sentences than for emotionally neutral sentences (underlined in Table 3). However, for channels 34, 36, and 44, the average Hb concentration changes are higher for emotionally neutral sentences than for emotionally toned sentences (underlined in Table 3). We analyzed the signals for these channels using t-tests ($\alpha = 0.05$). Table 4 presents the t-test results for the channels and the emotions whose presence or absence in sentences led to significant differences.

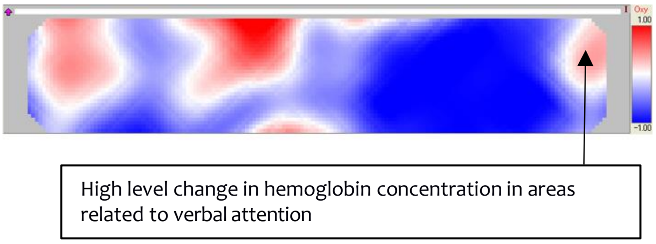
TABLE IV

T-TEST RESULTS FOR HB CONCENTRATION CHANGES FOR CHANNELS 11, 34, 36, 44, AND 47 BETWEEN EMOTIONALLY TONED AND EMOTIONALLY NEUTRAL SENTENCES.

Channel #	Emotions	Pearson correlation	t stat	P(T<=t)
11	Sadness	0.9963	−2.5307	0.0178
34	Fear	0.7858	2.5825	0.0158
36	Fear	0.8358	2.8177	0.0091
44	Fear	0.8839	2.2325	0.0344
47	Fear	0.8361	2.4671	0.0205

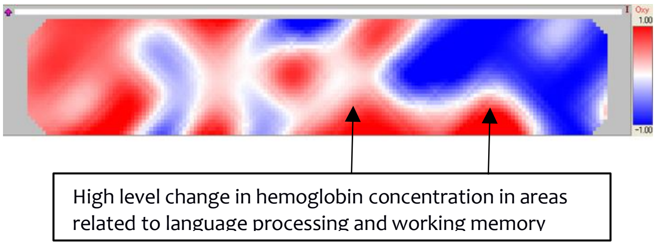
Table 4 illustrates the t-test results for channels 11, 34, 36, 44, and 47. Only channel 11 demonstrated significantly higher Hb concentration changes when subjects listened to sentences with the emotion of sadness than when they listened to emotionally neutral sentences. Channel 36 demonstrated a significant difference ($p < 0.01$) when subjects listened to sentences with and without the emotion of fear.

Using NIRS, we observed the relative changes in blood Hb concentrations in the brain and confirmed that the emotional intonation of sentences affected the brain activity of the subjects, especially in the frontal cortex and the areas associated with linguistic tasks. The total Hb concentration changes in the subjects' brains recorded during the experiment were mapped onto 2D images of the brain, as shown in Fig. 6.



High level change in hemoglobin concentration in areas related to verbal attention

(a) With emotion



High level change in hemoglobin concentration in areas related to language processing and working memory

(b) Without emotion

Fig. 6. Optical topography images showing relative changes in oxy-Hb concentrations in the brain of a male subject listening to a Malay sentence.

Figure 6 presents optical topography images that illustrate the relative changes in oxy-Hb concentrations in the brain of a male subject listening to a sentence (a) with and (b) without the emotion of fear. The images from subjects listening to emotionally toned sentences reveal that a part of the frontal cortex near Brodmann area 9 (BA9) experienced higher levels of changes in Hb concentration. These images suggest that the areas for short-term memory and verbal attention, both of which roughly correspond to BA9, were more activated than other brain areas when subjects listened to emotionally toned sentences. This result has also been demonstrated by other studies [16], [18]-[19]. Additionally, numerous studies have concluded that the right hemisphere in BA9 suppresses sadness and is involved in working memory, spatial memory, and emotion recognition [20]-[22]. The NIRS signals from channel 11, which was positioned roughly at the right hemisphere in BA9, demonstrated higher levels of Hb concentration changes (Figure 6[a]). This area is also involved in emotional word processing [23]-[24]. Therefore, a higher Hb concentration in this area suggests that subjects paid more attention to emotional context than the linguistic sounds themselves when listening to emotionally toned sentences.

On the contrary, the areas corresponding to language processing, including BA44 and BA45 (roughly corresponding to Broca's area and part of Brodmann area) and BA10 (corresponding to working memory), tended to show higher Hb concentration changes when subjects listened emotionally neutral sentences [25]. In particular, channels 34, 36, 44, and 47, which were positioned approximately in BA10, detected higher activation in these areas for emotionally neutral sentences than for emotionally toned sentences. Additionally, channels 37 and 48, which roughly corresponded to Broca's area, also detected higher Hb concentration changes for emotionally neutral sentences than for emotionally toned sentences. These results indicate that the language area of the brain was activated.

IV. CONCLUSION

Herein, we experimentally identified the effect of language sounds with emotional intonation by measuring brain activation using NIRS. The Malay language was used because it is a new language for the subjects of the study. Using the results, we analyzed the activation of the language areas of the subjects' brains. According to these results, when the subjects listened to emotionally toned language sounds, they showed activation in brain areas related to emotion and attention and less activation in language areas. These results suggest that emotional context activates brain areas related to emotion and attention. This is supported by a study by Kensinger et al., which states that emotional stimuli seem to grab attention [26]. A study by Minagawa–Kawai et al. also states that vocal emotions are linked to significant activation of the right temporal area, which is an emotional region of the brain [27].

Although the subjects of this study did not understand the language they heard, they were able to extract emotion from its sounds. Consequently, this served to enhance their brains' attention. On the contrary, listening to a non-emotional context led to activation in brain areas linked to language processing and working memory. We believe that the results of this study can be used to aid in the development of human–robot communication, as machines are becoming increasingly important for communication tools. Although the ability to interpret emotions may currently be a challenge in computer systems and robotics, in the future, integrating emotion into robots is expected to take place. Azeem et al. argued that it is quite possible to have human-like emotions in robots [1]. In fact, developing computational models of emotions is becoming increasingly important in the field. Furthermore, research on human–robot interaction has already begun with the use of NIRS as a tool [13]. We hope that this study can assist in understanding the effects of emotional sound on brain function. In this way, improved communication can be promoted not only between humans, but also between humans and machines.

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