SHIBAURA INSTITUTE OF TECHNOLOGY

Cognitive Task Analyses for Effective Communication Systems Using NIRS Measurement

by

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"Acquire knowledge, and learn tranquillity and dignity."

Omar ibn al-Khattab

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Abstract

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Communication systems always keep evolving with technology. Communication systems nowadays not only involved living things but also communication between living things and non-living things. However, several challenges occur such as limitation application on the robot in the aspect of cognitive. Cognitive play a crucial role in communication systems. By enhancing cognitive ability, human communication systems can be improved. Besides, by observing the cognitive process, the whole systems of communication can be advanced to robot communication systems.

This dissertation mainly focuses on two cognitive processes: emotion and working memory. Most of the cognitive studies only consider psychological effects. Therefore, this dissertation will discuss the cognitive task effects on brain functions by using brain imaging techniques. The tasks based on the cognitive processes has been designed. We recruited Japanese native speaker for performing the task while their brain activity been observed using near-infrared spectroscopy (NIRS) brain imaging technique.

Language area of the brain which always located at the left hemisphere of the brain has been focused. A language sounds that could not be understood by the subject, which is Malay language and the reversed Japanese language, had been induced with emotion. The subjects listened to the language sounds and guess the emotion intended. The brain observation results proposed that emotion is important

in some situation for communication with familiar language. On the other side, emotion might be also an obstacle, especially for new language acquiring.

In term of working memory, we investigated different background colours effects on brain activity. Circle counting task (CCT) and reading span task (RST) has been designed on different background colours. The subjects performed the tasks on the tablet while their prefrontal cortex of the brain been observed using NIRS. The prefrontal cortex of the brain corresponds to the working memory area. The measurement results suggested different background colour affects brain activity in varied ways.

Common background colour with black text, which is white background colour, could be used to enhance working memory especially for those who experienced ability deterioration. However, the combination of blue-green background colour and black text may be preferable for improving users' task performance. Both cognitive processes study results may be utilised in several fields including medical therapy, communication technology advancing and even improving the quality of people's lives, where all of these tools concern effective communication systems.

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Chapter 1

Introduction

This chapter introduce the overall of the study, which include the overall discussion on the ideas that led to this study which entitled ”Cognitive Task Analyses for Effective Communication Systems Using NIRS Measurement”. This chapter also includes the main objectives and contributions are described to clearly outline the scope of this study. Finally, the organization of this dissertation is presented.

1.1 Communication systems

Communication is an act of exchanging information by using a medium. The communication systems always involved the sender, receiver, and message. Nowadays, the evolution of communication systems proclaimed that our technology keeps emerging with changes. Face to face communication with the language spoken or body gesture as the medium, then writing by using symbol; or alphabet. Currently, all these systems are still in well used and with the presence of the technology, smartphone or tablet computer has been a part of the important aspects of communication.

In addition to human-human communication, new communication systems such as human-robot and robot-robot communication also emerged. Human-computer interaction (HCI), brain-computer interface (BCI), artificial intelligence (AI) and others are also widely known terms which have related to communication. HCI focuses on computer design, in particular, the design for interaction between human which is the users and computers. Initially, the researchers aimed at improving the usability of computers. Over time, HCI has expanded and become more diverse with the rise of technology.

HCI covers many disciplines including the design and deployment of digital health technologies [2]; the role and engagement in interactive art [3]; the visualisations of agricultural systems support [4]; communicative learning for education [5] and many more. Differs from HCI, BCI is originally a communication system to support the needs of people with physical disabilities for giving commands to the computer with brain activities. With the emerging of AI, the technology allowing the use of brain activity for the simulation of human intelligence to control the machines such as to conduct action or command.

1.2 Cognition and communication

Cognition is related to mental action or process to understand things throughout experiences and senses. Cognition usually includes a lot of processes such as language, emotion, memory, attention, learning, and others based on one's experiences and abilities. Each cognitive process plays an important role in communication. Language is a medium that we use to communicate either spoken or written. Expression in communication typically with the presence of emotions. Language usually coexists with the thought in understanding the information that we have received through communication.

Learning is a cognitive process that includes things as diverse as behaviours or habits. Piaget's stated that learning is the process of information that enters our cognitive system and changing it [6]. Attention has a relation with learning for us to be able to concentrate or pay attention to the stimuli while learning. Perception can be considered as a gate of the cognition where we use our senses, like sight, hearing, taste, smell, and touch. Memory is the cognitive process that acts as a nucleus in cognition that allows us to code, store, and recovers information from the past.

Recently, cognition is becoming a hot topic for researchers from various field. The researches not only limited for enhancing the cognitive systems, but these cognition processes also have been applied in the technology. For example, a cognitive process of emotion has been proposed in the communication systems for HRI [7]. Besides, the role of cognitive abilities has been observed for the development of communication skills in human [8]. Both people cognitive enhancing and cognitive technology implementing may progress in a parallel way. Those experience ability deterioration especially elderly people might need to enhance their cognitive. As the global population ages, seniors were not reliant on communication technology during their younger, appropriate environment for their lives must be established [9].

One cognitive ability that plays an important role is a memory. Memory declining is a crucial problem as the cognitive process relies more on it. Memory is partitioned into several parts—primarily short-term memory, long-term memory, and working memory. Short-term memory is the process where our brain stored the information for a short time. When the information is kept repeating, the information will be transferred into long-term memory. However, working memory involved in the complex situation including manipulated the information. This dissertation conducted a study to observe the human cognitive process in different situations. The different situations in this dissertation refer to the people condition that will be induced by the different processes of cognition, where it concerns the wellness level relates to emotion and memory especially working memory.

1.3 Related works

1.3.1 Emotion in communication

Human communication always involves speech recognition systems, which interpret emotions to obtain information. Emotions in a human communication system are thus necessary to achieve mutual understanding. Psychological studies argue that emotional factors influence the allocation of recognition and attention to context [10][11]. Both Ohman and Brosch examined the allocation of recognition and attention by using the visualised emotional factors. Nevertheless, studies of emotional effects induced by language are still rare. Only a few studies investigated emotional effects on subsequent language processing, and in most cases, these effects were induced by non-linguistic stimuli such as films, faces, or pictures [12].

Laura *et al* used visually linguistics stimuli in order to investigate on how emotional context of discourse affects language comprehension. They used electroencephalography (EEG) and discovered that short paragraphs can successfully elicit emotional states that impact language processing [12]. A study by Filik *et al* also using the same approach which investigated the emotion effects of a written context [13].

Another study by Aya Ihara *et al*, investigates the language comprehension dependent on emotional context by observing neural activities using magnetoencephalography (MEG). She used a cross-modal priming paradigm with auditorily presented emotions and visually presented language targets. Her findings suggested that language can be interpreted differently depending on the emotional context pervaded in it [14].

As proposed independently by the psychologist, William James and physiologist, Carl Lange, the experience of emotion are the results of physiological reactions to an event happened. The James-Lange theory indicates that physiological change triggers the emotional arousal when the brain reacts to the information received via the body's nervous system. The physiological changes such as muscular tension, increase heart rate, perspiration, dry mouth and running occur first before we feel emotion. Though it has been criticized and revised many times, the recent study asserts that the theory has been hard to disprove. Regardless of the theory, emotion is complex and there is no consensus on a definition.

1.3.2 Colour in communication

ICT has been used to assist people to communicate and even to improve their learning and training to maintain their health. However, in this super-aged society, elderly people are often shy away from technology, isolated and under-stimulated. This is because of their ability declining causing a difficulty for them to adapt with the technology. Therefore, the interface design now starting to take into account the usability regardless user generation. However, the design usually only consider psychological effects and the performance of the users.

Background colour is one of the component of the Information and Communication Technology (ICT) device screen. Several studies of text and background colour combinations have also been conducted [15][16]. These studies were only considered users' opinion and evaluation. From that, Mehta and Zhu took an approach in exploring the effect of colour on cognitive task performances [17]. They suggested that background colours could affected cognitive performances. Not only that, a study by Chan suggested that tablet computers also could enhanced cognitive functions of memory especially for elderly training [18]. Again, these studies were based solely on psychological effects and the users' performance.

A study of colour in relation to cognitive process by using neuroimaging is still rare. One study observing the haemoglobin (Hb) concentration changes in brain has suggested that the design of the screen could affect attention, concentration, and performance [19]. Chris *et al* also investigated the processing of colour preference in the brain by measuring the blood oxygen-level dependent (BOLD) activity [20]. Yamazaki examined if the background colours of computer- and Web-based tests affected the test scores of university students and suggested that neurological factors related to colour did affect test scores [21].

It has been said that the effective and comfortable screen design could boost the efficiency of the people brain and performance. Cognitive functions such as working memory is very important for communication. Therefore, the various characteristics of screen design and how they affect the brain of the users need to be examined.

1.4 Objectives

1. To assess the effect of the emotional context of language sound on brain functions:

With an understanding of emotional influenced language sounds, the author hopes that the data obtained from this study can provide some additional data in developing an effective method for improving and acquiring communication skills. The ability to understand feelings is essential in human communication. In everyday life, language is often used as a powerful tool to elicit emotions. Literature and poetry are magnificent examples of how language can make us feel deep emotions.

The same sentence may be interpreted differently depending on the emotional context, whether words are spoken in a happy, sad, or angry tone. Hence, emotion plays an essential role in the establishment of effective communication and good personal relationship [14]. Emotion can be aroused by auditory, visual, gustatory, olfactory and somatic perception. Therefore, in this study the author decides to investigate the the effects of emotion in language solely on auditory linguistics stimuli approach in order to obtain precise data and results.

This dissertation also aims to provide the results that can be used by another component of the system for communication. Nowadays, machines that express emotions are no longer science fiction [22], and they are studied in the field of affective computing [23]. Affective computing involves emotional information that machines interpret, express, manage, and respond to the users [24]. Consequently, machines must 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. Many studies have investigated artificial and emotional intelligence to improve methods of communication, including robot–robot communication [25][26][27].

These studies often regard human communication as an ideal model for human-robot communication, especially for voice-emotion recognition, with a strong emphasis on communication between robots and humans over long periods [28]. By understanding human communication systems, it is possible to apply them to robot communication systems. 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 [24].

2. To observe the effect of performing tasks on different screen background colours on brain functions:

As new technologies are emerging, to promote a better life, this dissertation aims to implement the results to provide a service for HCI of ICT where it will be easier and faster in comparison to a conventional method. Therefore, the result of this research will contribute to designing of effective and comfortable screen backgrounds that meet the needs of the people especially to those with the psychological burden towards these new technologies.

It is important to find a way with the design and environment for ICT that can provide better concentration ability for the users. The author also hopes that the results of this study could contribute to improving the quality of life in communication especially for the elderly since the ageing population is a serious social problem. The percentage of elderly people in the world population is expected to increase in the future [29][30]. Therefore, increasing their quality of life is important [31], because ageing causes a serious decline in cognitive abilities and a corresponding decline in the quality of life [32].

Since background colour is one of the important characteristics of the ICT device, the author decides to investigate the effect of proper background colour to enhance users' cognitive ability and performance especially those elderly people with ability deterioration. The study will focus on cognitive functions such as working memory and concentration since these functions are closely related to communication. Thus, we hope the results of this study could give a big help in every sector in term of communication such as education, service, healthcare, economy and other sectors of a country. In education, it could help people to learn in an effective and conducive way. On the other hand, for economic sectors, it can boost worker efficiency and could increase company performance.

In general, this dissertation aims to contribute to the community by providing the results with well-being recognition where it will help improve and promote better communication systems. In this study, by using a near-infrared spectroscopy (NIRS) system, this researches will attempt to investigate the activities of the brain when the subjects are exposed to different situations. Spectroscopic measurements have been performed to obtain the relative concentration changes of the oxygenated Hb (oxy-Hb), deoxygenated Hb (deoxy-Hb), and its total Hb in real-time using diffuse optical techniques. The final results of the combination of multiple studies of this dissertation will be discussed later in Chapter 4, 5, and 6. Finally, the dissertation aims to contribute to society by suggesting effective communication systems in daily life.

1.5 Structure of this dissertation

The rest of the dissertation is organized as follow: Chapter 2 discusses the brain functions that have related mainly with communication. Chapter 3 demonstrates the brain imaging technique that will be used for this study. Chapter 4 discusses the first part of this study which is the effect of language sound-induced with emotions on brain activity. In Chapter 5, it discusses the second part of this study, where we observed brain activity while performing the task on different background colours. Finally, Chapter 6 concludes the study along with the discussion regarding future works opportunity of this study.

Chapter 2

Brain Functions

In this chapter, the brain functions which relate to the study is discussed. The chapter focuses on explaining the functions of the brain based on the regions.

2.1 Brain function localization hypothesis

The brain function localization hypothesis assumes that brain functions are locally distributed in the brain. This means that there is a relationship between the parts of the brain and its ability to function when performing a certain task. Brain parts such as visual cortex, auditory cortex, motor cortex, and so on, have different features and represented clearly by different areas in the brain. However, in recent years, there is an idea proposing that the parts of brain functions are not as simple as one-to-one connections, but rather many parts of the brain function as a network inside of the brain. To simplify the analysis in this study, an experiment was conducted and the conclusion of this study was drawn, based on the brain function localization hypothesis.

2.2 Brodmann areas (BA)

Brodmann areas were originally defined and numbered by the German anatomist Korbinian Brodmann based on the cytoarchitectural organization of neurons he observed in the cerebral cortex. Using the newly developed staining technique of Nissl, Brodmann distinguished about 50 zones of the cortex based on subtle differences in cell type, size, density, and lamination, and correlated his anatomic findings with studies on the localization of function in humans, subhuman primates, and other mammals. His cortical map and numbering system, published in 1909, became standard methods for distinguishing areas of the cortex, and are still widely used by clinical neurologists and neurosurgeons.

Based on the brain function localization hypothesis, Korbinian Brodmann differentiated the cerebral cortex into the uniform part of nerve tissue structures by labelling them with numbers from number 1 to 52. These numbers represent the areas of the brain, which then are called Brodmann areas (BA). The characteristics of the cell construction are related to the processing properties of neurons and indicate the laterality of the cortical areas of the brain in terms of their activities.

2.2.1 Language areas

The study of how language is represented, processed, and acquired by the brain is neurolinguistics, which is a large multidisciplinary field drawing from cognitive neuroscience, cognitive linguistics, and psycholinguistics. This field originated from the 19th-century discovery when physicians discovered that the left inferior frontal gyrus now known as Broca's area was essential in producing language, whereas the left superior temporal gyrus now known as Wernicke's area, was essential in understanding it. The language areas of the brain, which roughly correspond to the frontal lobe, consists of the grammar center, the text comprehension center, and also the center of phonological and word in the region from the temporal lobe over the parietal lobe [33][1]. Figure 2.1 shows the language areas of the brain.

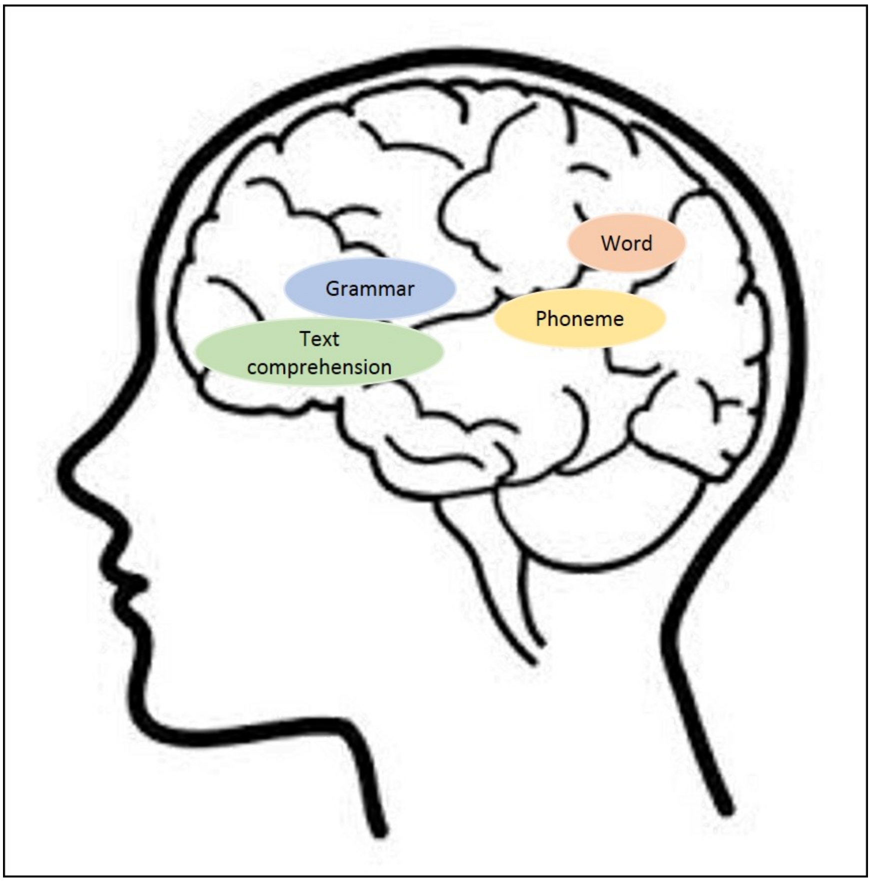


Figure 2.1: Language areas of the brain [1]

Broca's area

The process of identifying the parts of the brain that are involved in language began in 1861, when Paul Broca, a French neurosurgeon, examined the brain of a recently deceased patient who had had an unusual disorder. Though he had been able to understand spoken language and did not have any motor impairments of the mouth or tongue that might have affected his ability to speak, he could neither speak a complete sentence nor express his thoughts in writing. The only articulate sound he could make was the syllable "tan", which had come to be used as his name. When Broca autopsied Tan's brain, he found a sizable lesion in the left inferior frontal cortex.

Subsequently, Broca studied eight other patients, all of whom had similar language deficits along with lesions in their left frontal hemisphere. This led him to make his famous statement that "we speak with the left hemisphere" and to identify, for the first time, the existence of a "language centre" in the posterior portion of the frontal lobe of this hemisphere. Now known as Broca's area, this was the first area of the brain to be associated with a specific function, and in this case, language. Broca's area refers to the frontal lobe areas of the left side of the brain and corresponds to the BA 44 and 45. These areas play an important role in language processing. This is because it is at the part where activities occur for language uttering, grammar processing, and text comprehension. Figure 2.2 shows the position of Broca's area in the brain.

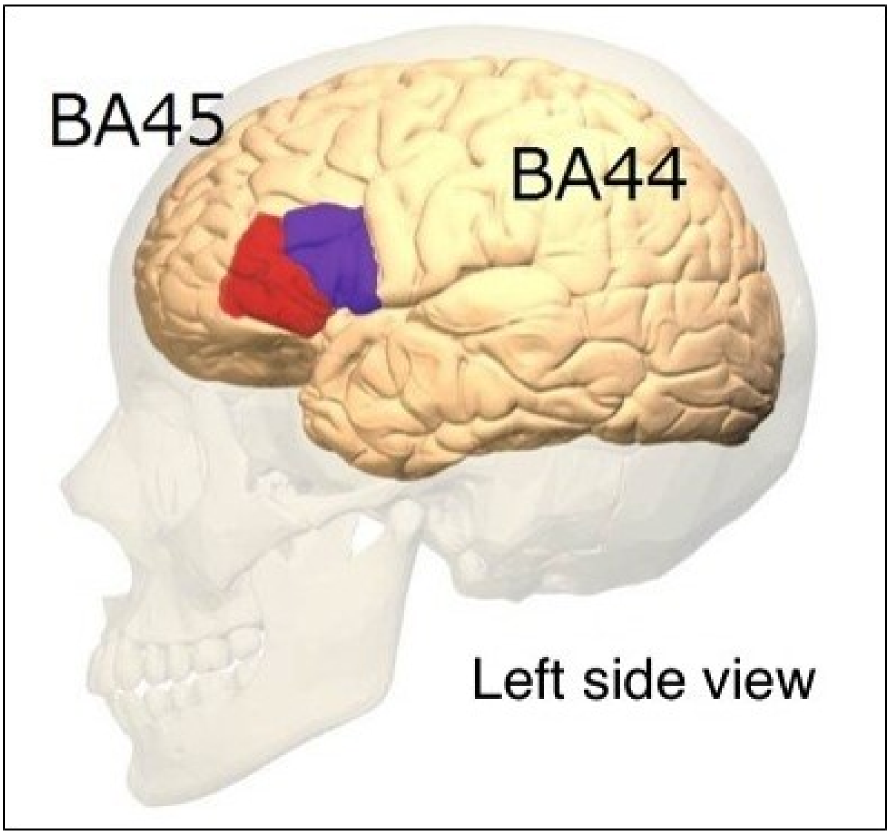


Figure 2.2: Position of Broca's area (The original image was obtained from BodyParts3D, and the image was modified for this paper.)

Wernicke's area

Ten years later, Carl Wernicke, a German neurologist, discovered another part of the brain, this one involved in understanding language, in the posterior portion of the left temporal lobe. People who had a lesion at this location could speak, but their speech was often incoherent and made no sense. Wernicke's observations have been confirmed many times since. Neuroscientists now agree that running around the lateral sulcus in the left hemisphere of the brain, there is a sort of neural loop that is involved both in understanding and in producing spoken language. Wernicke's area refers to the left hemisphere of the brain that corresponds to the BA 22.

In this area, the brain is active when processing words and understanding language spoken, similar to the language processing areas of the Broca's area. At the frontal end of this loop lies Broca's area, which is usually associated with the production of language, or language outputs. At the other end (more specifically, in the superior posterior temporal lobe), lies Wernicke's area, which is associated with the processing of words that we hear being spoken, or language inputs. This language loop is found in the left hemisphere in about 90% of right-handed persons and 70% of left-handed persons, language being one of the functions that are performed asymmetrically in the brain.

When we are talking about language, it is useful to distinguish between verbal language (the literal meaning of the words) and everything that surrounds these words and gives them a particular connotation. This is a big difference between denoting and connoting: the message that is perceived never depends solely on what is said but always on how it is said as well. A good reason to distinguish between the denotative and connotative aspects of language is that they call on different parts of the brain. In the great majority of people, it is the left hemisphere that formulates and understands the meaning of words and sentences, while the right hemisphere interprets the emotional connotation of these words.

2.2.2 Working memory areas

Short-term memory can be referred to as "the brain's Post-It Note". This can be thought of as the ability to remember and process information at the same time [34][35]. It holds a small amount of information for a short period. For example, to understand this sentence, the beginning of the sentence needs to be held in mind while the rest is read, a task which is carried out by the short-term memory. Other common examples of short-term memory in action are the holding on to a piece of information temporarily in order to complete a task (e.g. “carrying over” a number in a subtraction sum, or remembering a persuasive argument until another person finishes talking), and simultaneous translation (where the interpreter must store information in one language while orally translating it into another).

However, this information will disappear soon, unless we consciously try to keep it. Short-term memory is a necessary step towards the next phase of retention, long-term memory. The transfer of information to long-term memory for more permanent storage can be assisted or improved by the repetition of information, or more effectively by giving meaning to it and associating it with others knowledge acquired previously. Motivation is also a consideration, in that information relating to a subject of strong interest to a person, is more likely to be retained in long-term memory.

The term working memory is often used interchangeably with short-term memory, but technically working memory refers to the entire theoretical framework of the structure and process used for temporary storage and manipulation of information, where short-term memory is only a component. The working memory areas of the brain roughly corresponded to the dorsolateral prefrontal cortex (DLPFC) of the prefrontal cortex. This region lies in the middle frontal gyrus of humans, which is the lateral part of BA 9 and BA 46. This region also covers BA 8 and BA 10. The positions of BA 9, BA 10, and BA 46 are shown in Figure 2.3.

BA 9 is part of the frontal cortex. This area is involved in short term memory, overriding automatic responses, verbal fluency, error detection, and auditory-verbal attention. BA 10 is the anterior-most portion of the prefrontal cortex in the human brain. It occupies the most rostral portions of the superior frontal gyrus and the middle frontal gyrus. The present research suggests that it is involved in strategic processes in memory recall and various executive functions. Both BA 9 and BA 10 regions are associated with the retrieval of memory, recognition, and decision-making [33]. Since BA 46 also lies in the DLPFC, it plays a central role in sustaining attention and managing working memory.

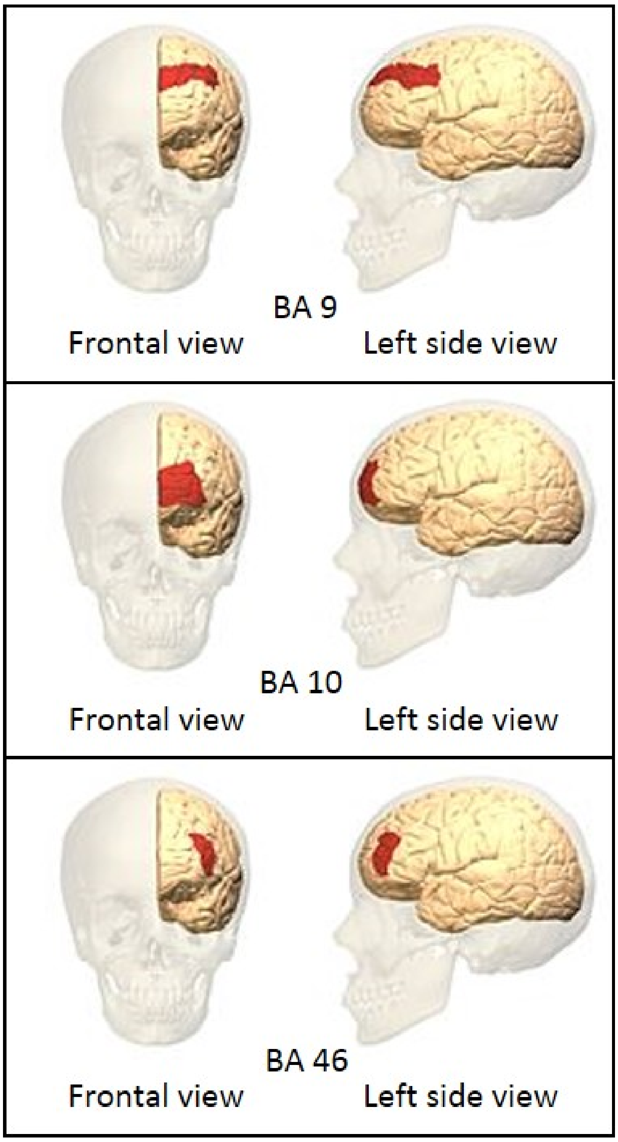


Figure 2.3: Position of BA 9, BA 10, and BA 46 (The original image was obtained from BodyParts3D, and the image was modified for this paper.)

2.2.3 Other Brodmann areas

BA 8 is located near the frontal pole. It is also called as the frontal eye field and is activated when there is an eye movement and visualisation. BA 8 is also activated when it encounters a task that is not convinced and it is also a part of the grammar centre [33][36][37]. BA 11, which is located at the above the eye sockets, is involved in decision making. It is also functioned in encoding new information into long-term memory [38]. Figure 2.4 shows the position of BA 8 and BA 11 in the brain.

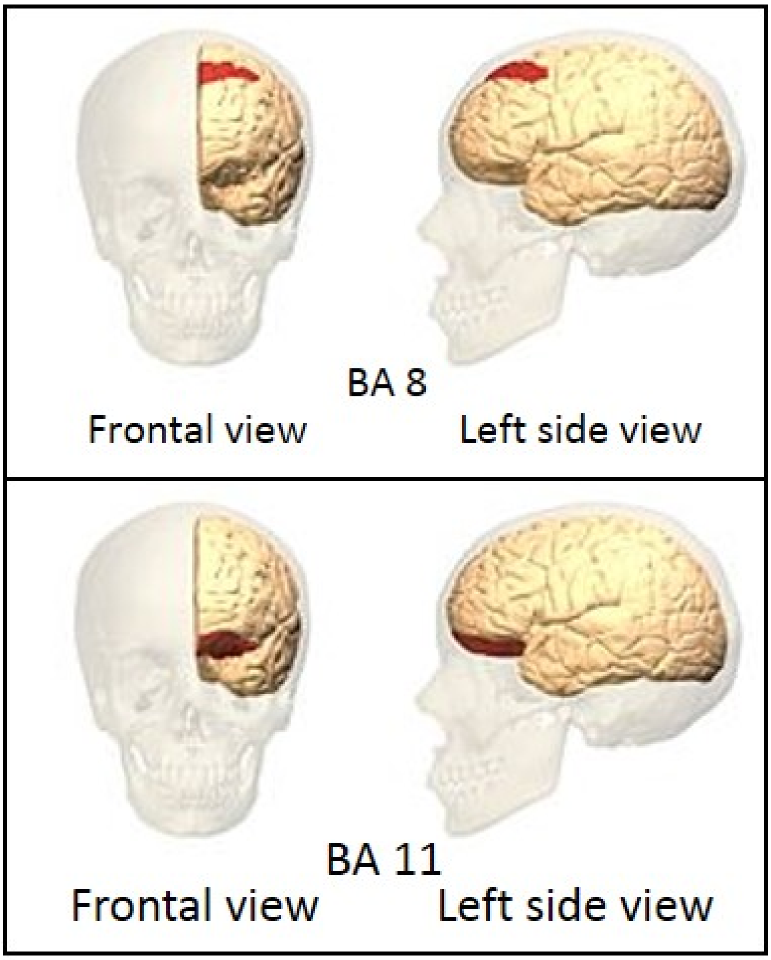


FIGURE 2.4: Position of BA 8 and BA 11 (The original image was obtained from BodyParts3D, and the image was modified for this paper.)

2.3 Conclusion

Brain regions involved in very complex structures and can be engaged in many different behavioural functions. In this study, the author only focused on regions that have relation to communication. The frontal part of the brain for working memory and also the left hemisphere for language. Language areas located at the left hemisphere of the brain will be investigated by using a brain imaging technique. The emotionally induced language sounds as the cognitive task will be used in the study to observe the brain activity of the language areas.

On the other hand, the working memory of the frontal part is a crucial process for communication. Working memory area also will be assessed using brain imaging technique and working memory task on different background colours will be tested on the subjects. It is hoped that the study results can play big roles in communication systems from assessing these brain areas.

Chapter 3

Brain Imaging Technique: Near-Infrared Spectroscopy (NIRS)

In this chapter, the brain imaging technique system is discussed. The chapter focuses on explaining the mechanism of the brain imaging technique that has been used in the study. Furthermore, it describe other techniques for the comparison with the technique used.

3.1 Near-infrared spectroscopy (NIRS) system

Near-infrared spectroscopy (NIRS) is a non-evasive, non-ionizing imaging technique that offers the ability to perform real-time studies in human subjects' brains. NIRS is an invaluable tool that has shown its potential in the application of brain imaging. This technique has been applied to many different areas of the brain. NIRS offers a therapeutic window which allows for the separation and quantification of both oxygenated haemoglobin (oxy-Hb) and deoxygenated haemoglobin (deoxy-Hb).

NIRS relies on the light in the range of 600[nm]-1000[nm]. As light propagates through the various tissues it encounters in the body, light in this region is minimally absorbed, and preferentially scattered, allowing for separate signals to be obtained at multiple wavelengths. Light, after being absorbed and scattered at the cerebral cortex, is condensed by optical fibre again at a distance of about 30[mm] from the surface of the head.

These events cause the light to lose intensity, and the detected light seen by the photon detector has less intensity than the initial intensity of the light that was launched with. Once each wavelength of light has been collected by photon detectors at the tissue surface, separation of light based on specific wavelengths allows for the back-calculation of the relative concentrations of both oxy-Hb and deoxy-Hb [39].

To apply the technique of NIRS to brain imaging, an array of laser sources is created and placed on the region of interest, or the entire head. As previously mentioned, NIRS is minimally absorbed by the body, which allows for sampling of the outer 15[mm]-2[mm] of the head through the skin and skull, to reach the outer 5[mm]-10[mm] of brain tissue, approximately. Light sources emit light into the skull, where the photons become highly scattered, and usually exit the skull 3[cm]-4[cm] away from the light source. By placing detectors roughly 3[cm] away, the light signal is passed through the head can be collected over a diffuse volume.

In the brain, changes in the optical absorption are related to the changes in both oxy-Hb and deoxy-Hb. Both the relative concentration of oxy-Hb and deoxy-Hb can be estimated from the optical measurements of the changes in the absorption at multiple wavelengths. This is due to the unique absorption signatures of the oxy-Hb and deoxy-Hb. The changes in relative concentrations of both haemoglobin species in the brain are usually in response to a given activation or stimulation task and are known as functionally evoked responses.

3.1.1 Data, probe and channel

A NIRS system consists of irradiation/detection probes and a signal detection processing unit. Near-infrared rays are irradiated to the scalp and scattered inside through the irradiation probe that is fixed to the head, then the detection probe detects the rays. A measurement region, which is between the irradiation probe and the detection probe, is called a channel, as shown in Figure 3.1. NIRS data consists of a series of time-dependent signals measured between an individual light source and detector positions on a probe. The concentrations of oxy-Hb, deoxy-Hb and total haemoglobin (Hb) can be calculated for each source-detector pair.

It is possible to switch between 2D, 3D, and other thermography formats visually. However, we used a 2D image format represented by colour shading to help us easily understand the data. The typical measurement data displayed in three stages; oxy-Hb, deoxy-Hb, and total Hb concentration changes. Since the relationship between the display region and the channel varies depending on the experiment, it is necessary to pay attention at the time of observation. Due to the growth of the NIRS field, there are now an abundance of commercially available optical instrumentation systems: Imagent ISS, NIRO 500, Hamamatsu, and Hitachi, to name a few.

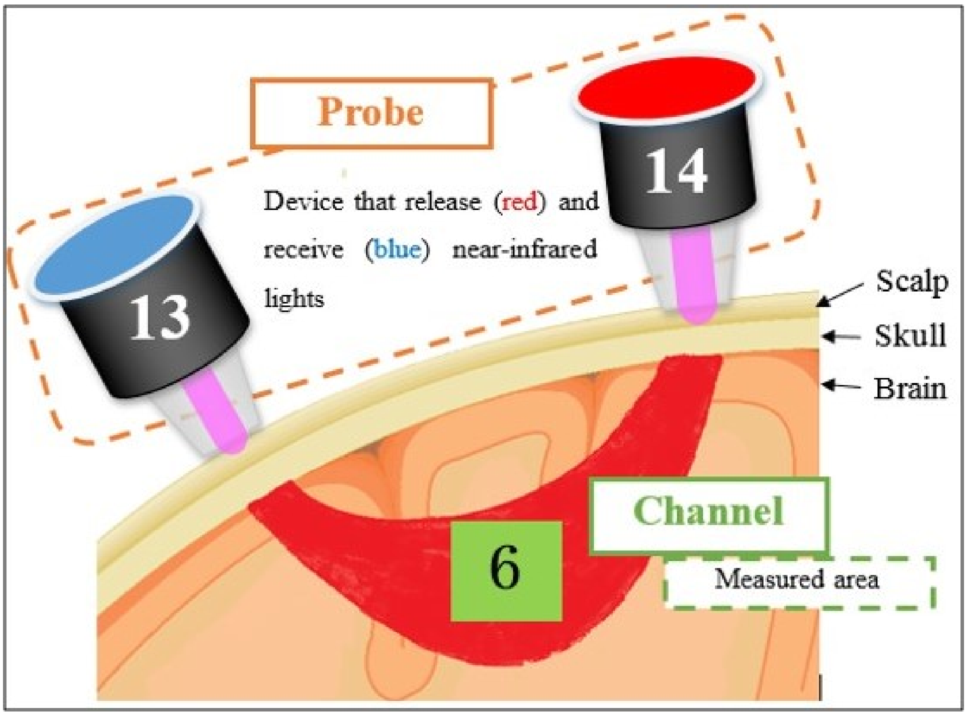


Figure 3.1: Mechanism at NIRS probes

3.2 NIRS signal processing and analysis

There are two types of data analysis methods for oxy-Hb and deoxy-Hb concentration change: (1) analysis using a generalized linear model (GLM) and (2) analysis using a normalized averaging waveform. GLM analysis extracts the intensity of the component that changes along with the ideal brain activity pattern from the measured data, and compares it between conditions and between channels. The model waveform is given in advance according to the block design, for example, "Rest (0), Task execution (1)".

In the analysis using the normalized averaging waveform, the normalized averaging waveform is calculated in which the amplitudes of all measured data values obtained at a fixed baseline time during the measurement period. This method analyses the relative change in haemoglobin concentration between subjects or between different channels of the same subject after converting the relative change in concentration change into data that can be compared. Since the analysis method is simple and does not require the preconditions of the brain activity pattern in the analysis, it has the advantage that it can be applied to data that is performed only once or has a small number of trials.

In this study, the author analysed the data using the normalized averaging waveform. The standard deviation of the data value at 2[s] just before the start of the task with the sampling timing of 40 points is obtained from the average Hb concentration change data. Then, the value of the entire waveform data will be divided by it. It will be an index to show the recurrence the concentration change occurred during the task compared to the Hb concentration just before the start of the task. The reaction for brain activity took about several seconds after the start of the task and has a time-structured activity pattern that lasts several seconds to several tens of seconds. This is because it associated with the blood flow signal which has a metabolic reaction resulting from electrical activity in the brain [40].

3.3 Application of NIRS

In 1977, Jobsis was the first to demonstrate the technique of NIRS in measuring cerebral changes. Since Jobsis first demonstrated this technique, it has been applied in various regions of the brain including visual, auditory, and somatosensory cortices, as well as in the motor cortex, prefrontal cortex, and in language areas of the brain [41][42][43][44]. There have been numerous studies performed on the brain. These studies ranged from performing NIRS on the visual cortex of infants, to measuring motor cortex activation in response to some given stimuli. Other applications include studying visual cortex, auditory cortex, the somatosensory cortices, and the prefrontal region of the brain. Understanding of the brains function in response to communication has been a topic of major interest.

In recent years, NIRS has been used to study brain activity. Yamazaki and Eto conducted a study to investigate if circle counting task's scores differ, depending on the characteristics of white and blue background colours of tablet by using NIRS [45]. Besides, Noriyuki *et al.* investigated the effect of an auditory alert on a driver by observing prefrontal cortex activation using fNIRS [46]. Sachiyo *et al.* also used NIRS to examine the emotion-related blood flow changes in the ventral medial prefrontal cortex [47]. Furthermore, Canizo *et al.* used NIRS with the combination of aEEG and neuromarkers to assess the brain damage in pediatric cardiac surgery [48]. These studies have shown that NIRS is a useful measuring device for the study of the activity of the brain [33].

NIRS is an invaluable tool that has shown its potential in the application of brain imaging. Previous researches have shown that it provides a good spatial and temporal resolution, with the ability to detect relative changes of both oxy-Hb and deoxy-Hb in the brain, in response to various stimuli. To date, there have been numerous studies that looked into the activation, or functional connectivity, or lateralization, in various parts of the brain by using both NIRS and other modalities.

3.4 NIRS: Hitachi

Two types of NIRS by Hitachi that have been used in this study. The measurement items were oxy-Hb concentration changes, deoxy-Hb concentration changes, and total Hb concentration changes. In this study, the channels were used simultaneously to measure brain activity. The relative oxy-Hb and deoxy-Hb concentration changes and total Hb concentration changes for blood volume can be seen based on the state of the brain after the starting point of measurement. Not only the Hb concentration changes were being recorded during the measurement, but it is also possible to observe the measurement results in real-time. The results can be observed in a time course and mapping graph format. It is also possible to switch between 2D, 3D, and others topography format variously.

3.4.1 ETG-4000

A NIRS based optical imaging system developed by Hitachi Medical Corporation (ETG-4000) with 52 optical source-detector channels, as shown in Figure 3.2, was used to conduct this study. To properly ensure that a secure contact would be maintained for both sources and detectors with the scalp, and source distances would be constant, a custom-built optical head cap was utilized to place the sources and detectors on to the temporal region of the brain [49].

Figure 3.2: Image of the NIRS system (ETG-4000) used in this study

3.4.2 WOT-100

A NIRS system, Hitachi Medical Corporation WOT-100 Wearable NIRS, was used in this study, as shown in Figure 3.3. Sixteen channels were used in this study, to observe the brain activity of each subject. WOT-100 is a portable version of NIRS, and it is much more compact in size and convenient to operate. Furthermore, WOT-100 has been equipped with the head belt to ensure both sources and detectors have a secure contact with the scalp while operating the systems.

FIGURE 3.3: Image of the NIRS system (WOT-100) used in this study

3.5 Advantages and disadvantages

The advantage of NIRS in brain function measurements is, that NIRS is completely non-invasive and there is no adverse effect on the living body including infants even though it uses infra-red rays repeatedly in taking measurements. Besides that, NIRS can be measured every 0.1[s], which has a high time resolution and NIRS also mobile because it is small in shape. It is not only possible to measure in a natural posture, such as sitting and standing, but it is also feasible to measure while the utterance and movement.

However, the spatial resolution of NIRS is as low as about 1[cm]-3[cm], which is about at the gyrus in the brain structure. Mainly, the measurement at cerebral cortex cannot be measured for inner brain structures. The measured data shows relative changes from the Hb concentration baseline. The units, such as [mM mm] and [µM mm], represent with the product of Hb concentration and length. It also includes the scalp, muscle, and skull involvements. Therefore, the task is essential to detect changes caused, because task design is to ensure a controlled condition.

From its characteristics described above, NIRS can be concluded as a device to measure “the time course of activation reaction of the subject’s cerebral cortex of the natural state can be considered as a whole simple non-invasive examination” [39]. There is a commonality between electroencephalography (EEG) of the brain function and electrocardiogram (ECG) and ultrasound examination in these features. The expression ”conveniently considered as a whole” [39], rather than measuring the exact value including the optical path length problem, which refers to the methodology suitable for the function capture precisely. These problems come from the measurement principle of using the scattered light. It is desirable to consider these features completely when NIRS is used.

3.6 Other imaging techniques

Positron emission tomography (PET) is one of the imaging techniques. PET imaging detects trace amounts of short-lived radioactive material to map functional processes in the brain. PET imaging can diagnose, evaluate or treat a variety of diseases including neurological disorders. However, PET imaging uses radioactive material, it is invasive to the patients and not suitable for repeating examination. Computed tomography (CT) scanning is another imaging technique. CT scan may be combined with a CT scan for the examination. CT scan uses the differential absorption of x-rays and the subject need to lies on a table in a cylindrical apparatus.

Magnetoencephalography (MEG) measures the magnetic fields produces by electrical activity in the brain via superconducting quantum interference devices. Subject’s movement is often restricted during the MEG examination. Also, magnetic fields used by MEG usually can affect other devices. Electroencephalography (EEG) measures the electrical activity of the brain by electrodes and usually has been used for engineering studies. In spite of having a high temporal resolution, EEG can be affected by other electromagnetic signals outside the brain.

Functional magnetic resonance imaging (fMRI) is a very famous imaging technique. fMRI detects the changes in blood oxygenation in the brain. Like NIRS, fMRI also measures blood flow that occurs in response to neural activity. Both also did not affect by electromagnetic noise outside the brain. Unlike NIRS, fMRI has a good spatial resolution. However, fMRI is expensive and needs a specialist for operations. Also, fMRI is not flexible and portable and has a low temporal resolution which is about 3[s]-6[s]. Table 3.1 shows the comparison of NIRS with other brain imaging techniques.

Table 3.1: Brain imaging techniques comparison

Measurement	Spatial Resolution	Temporal Resolution	Non-invasiveness	Flexibility	Price
NIRS	Fair	Good	Very Good	Good	Fair
PET	Good	Poor	Poor	Poor	Poor
MEG	Good	Good	Good	Poor	Poor
EEG	Poor	Very Good	Good	Fair	Very Good
fMRI	Very Good	Fair	Good	Poor	Poor

3.7 Conclusion

In this chapter, the author discussed the brain imaging technique used in this study. These brain imaging technique will be installed on subjects' head to observe brain activity. It will observe the region that covered emotion and working memory, which were important processes for communication. A lot of studies have been using NIRS to observe brain activity. A study by Takayuki using NIRS systems to observe the changes of cerebral oxygenation during the reading span test among elderly subject [50].

In this study, ETG-4000 will be used in the experiment to observe language areas of the brain. ETG-4000 has 52 channels that will cover the language area that located at the left hemisphere of the brain. On the other hand, WOT-100 will be used to assess the brain areas related to working memory. Since WOT-100 has 16 channels, it only covers the frontal area of the brain which corresponded to working memory area. NIRS systems could help to investigate the brain activity significantly, thus it will be beneficially to this study.

Chapter 4

Emotionally Induced Language Sounds Effect

In this chapter, the details of the emotion process experiments are discussed. In order to assess the effect of the emotional context of language sounds on brain functions, this chapter will describes three different experiments. Each experiment will be discussed in section 4.3, 4.4, and 4.5 respectively in details. However, the methodology applied in the three experiments were almost the same and will be discussed separately in section 4.2.

Emotion Experiment I – Malay language with 5 emotions

Emotion Experiment II – Reversed Japanese language with 5 emotions

Emotion Experiment III – Reversed Japanese language with 3 emotions

Figure 4.1: Three experiments in Chapter 4

4.1 Emotion and language sounds

There have been many studies on emotional contexts and language processing. Most of the studies have found that the result of mood induction is a change in the performance of cognitive tasks. 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. Besides, we hope also the results could give help in finding a method to improve, thus enhance the cognitive ability of the brain. Many studies found that the left hemisphere of the brain is related to analytical and logical processing, while the right hemisphere tends to control spatial recognition and emotion processing [51].

However, recent research has demonstrated that the functional aspects of emotional comprehension are region-dependent [52]. Thus, we focused on the emotional effect on language areas that are located in the left hemisphere of the brain, even though the right hemisphere is known for emotion processing. We used a near-infrared spectroscopy (NIRS) system, which measures blood haemoglobin (Hb) concentration changes using near-infrared light to assess brain functioning. These brain-function measurements can provide a model to build a complex system for artificial life. Using NIRS, the effect of emotion on brain activity can be evaluated and utilized for cognitive enhancing and robot systems.

4.2 Methodology

Whole procedure of the experiments consist of three steps. The first step is language sound sample production. Next is follow with language sound sample verification. Lastly is the brain activity observation.

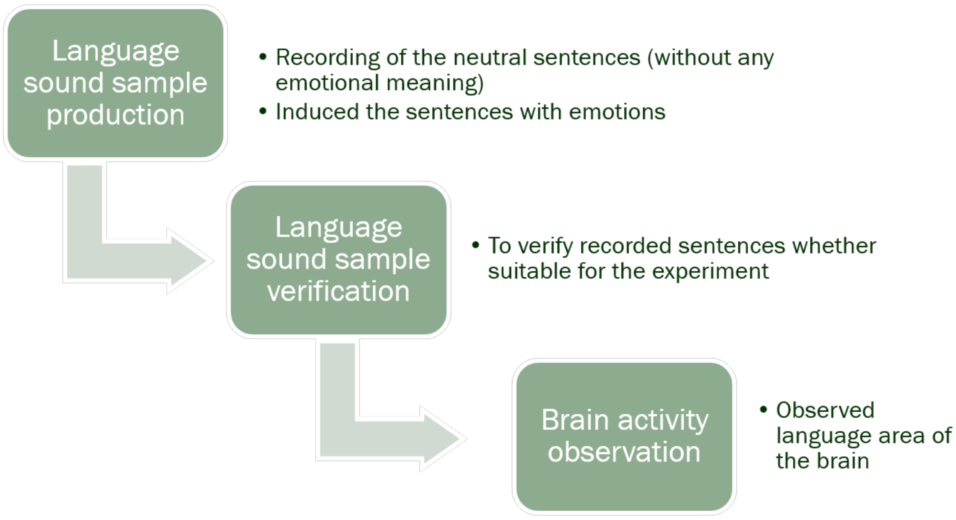
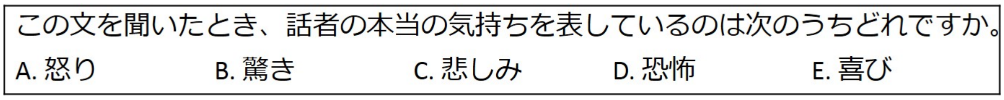


FIGURE 4.2: Procedure step of the experiment

4.2.1 Verification test

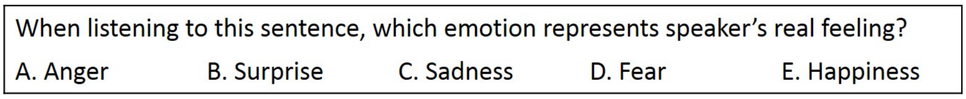
All procedures used in this research were approved by the Ethical Committee of Shibaura Institute of Technology. The verification test was conducted before the experiment. The verification test was to ensure that the recording and questionnaire prepared were fit and suitable for the experiment. For verification test, a class of students was asked to answer a survey on emotion recognition while listening to the recording of the language sounds. The subjects answered a questionnaire to show which emotion—either happiness, sadness, anger, fear, or surprise—they felt each language sounds expressed. An example of the questionnaire used in the study is shown in Figure 4.3 and its English translation is shown in Figure 4.4. The verification test will be discussed in details in the section of each experiment.



この文を聞いたとき、話者の本当の気持ちを表しているのは次のうちどれですか。

A. 怒り B. 驚き C. 悲しみ D. 恐怖 E. 喜び

Figure 4.3: Sample of the questionnaire



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

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

Figure 4.4: English translation of the questionnaire

4.2.2 Participants

Healthy right-handed subjects (males and females) were recruited to participate in this study. They were university students and graduate school students (between 18-26 years old), and their first language is Japanese. Since the left hemisphere of the brain is dominant for language processing in right-handed people, 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). Informed consent was obtained from all individual participants involved in the study, with all experiments being carried out at Shibaura Institute of Technology. Completion of the task required 10-15 minutes.

4.2.3 Experimentation

In this study, we used a NIRS system developed by Hitachi Medical Corporation (ETG-4000, 52 channels) to observe and record the Hb concentration of the brain of every subject in every 0.1[s]. Brain areas activation can be detected by the increments of the values of the oxygenated Hb (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.

As the preparation for the measurement, probes were secured to a holder patch attached to a cap. Since proper tightening on the head is crucial to this experiment, we used a swimming cap as the headgear to secure the probes and holder patch in place. Figure 4.5 shows the condition of the holder patch being secured to a cap. Probe numbers were printed on the holder. After confirming that the holder and cap were fixed, probes are then attached to the holder. The headgear included 52 optical source-detector channels to monitor relative changes in Hb concentration in subjects' brain. The complete set up of the headgear is shown in Figure 4.6.

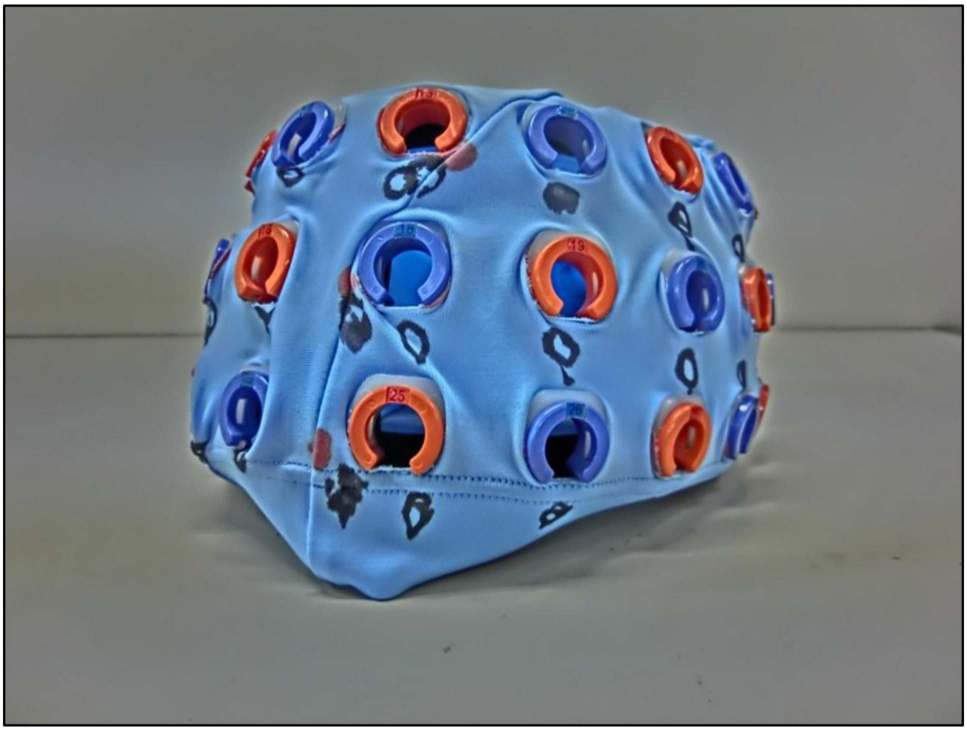


Figure 4.5: Holder patch secured to a cap

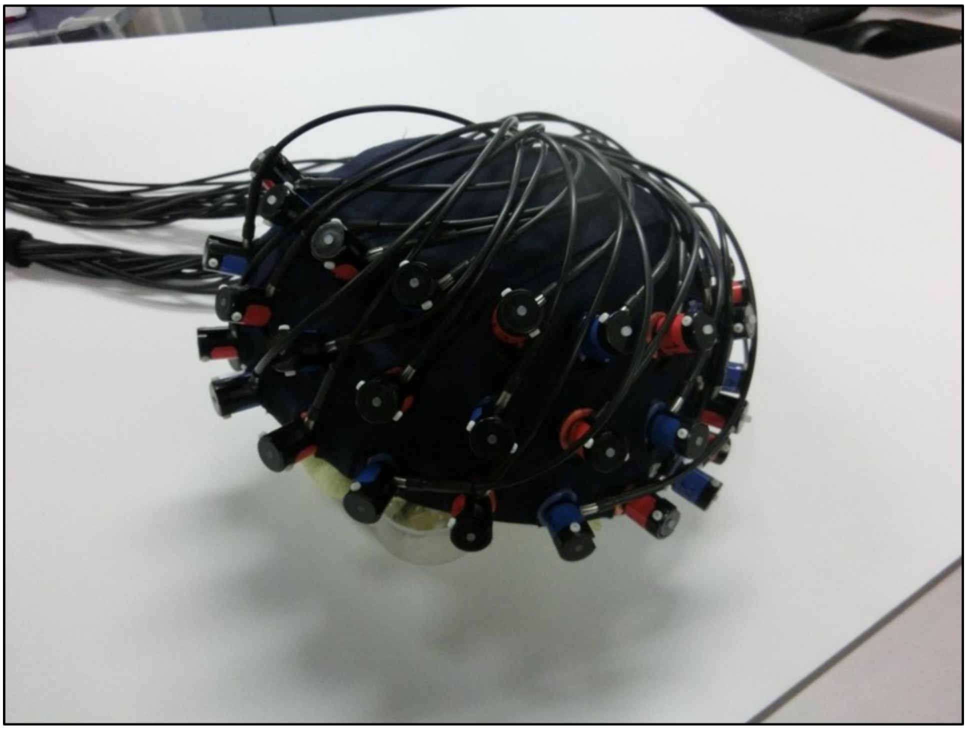


Figure 4.6: Headgear set up

After the headgear was ready, it was then applied to the subject's head. To assess the language areas of the brain, the channels are positioned to cover the left hemisphere of the brain, including a part of the frontal region of the prefrontal cortex, Broca's area and Wernicke's area. The mounting position of probes and NIRS measurement areas are shown in Figure 4.7. Figures 4.8 shows one of the male subjects with optical topography probes applied to his forehead and the position of the headgear.

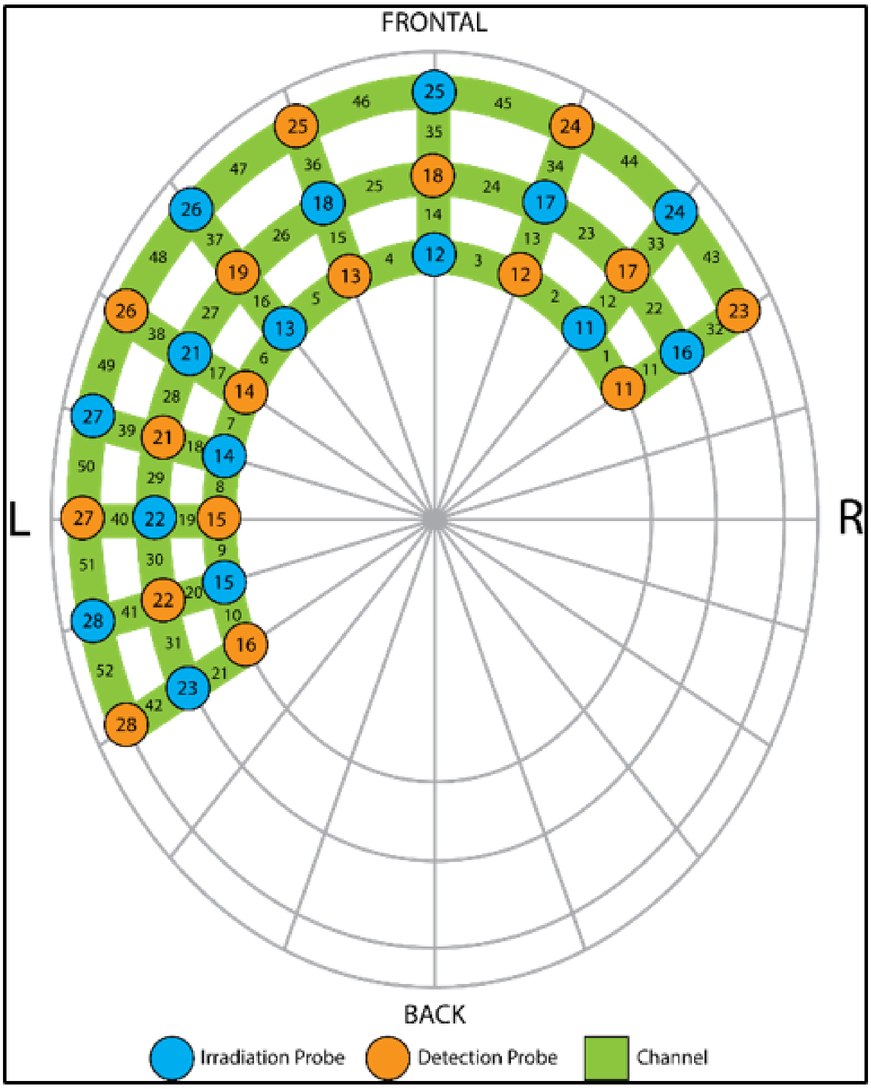
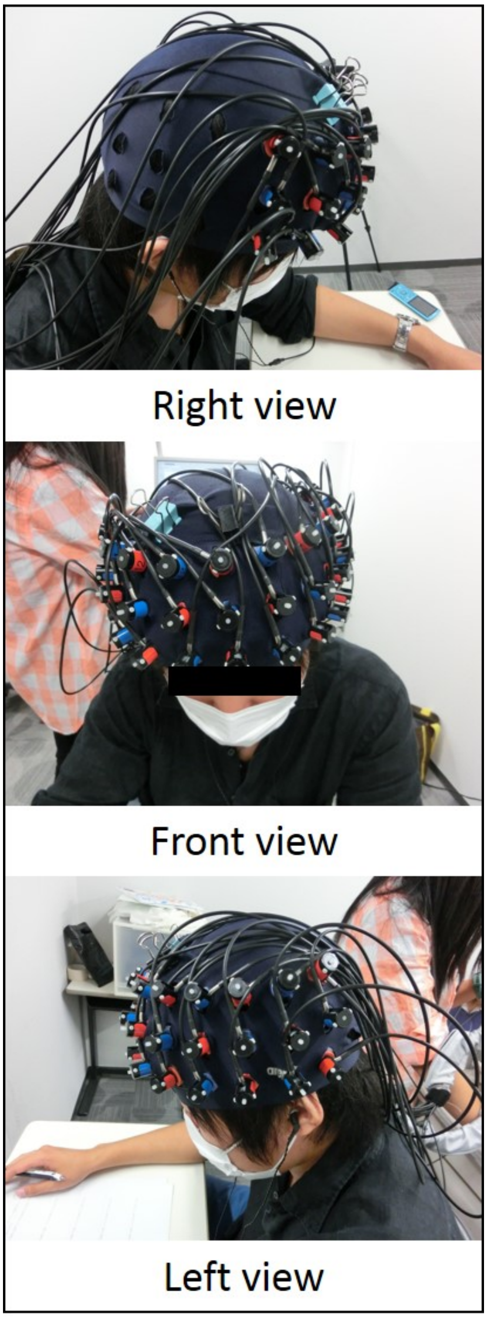


Figure 4.7: Channel mapping of NIRS ETG-4000



[redacted]

Figure 4.8: Positions of NIRS ETG-4000 probe on subject's head

Before starting the experiment, the signals were first tested to confirm whether they were properly acquired and irradiated using the utility provided in the NIRS system, as shown in Figure 4.9. If the signals were not properly received, the headgear was fixed and positioned once again until all signals were confirmed to be received by all channels. The complications were often due to the amount of subject's hair and the size of the head which can prevent the light radiation to reach the scalp. This experiment must not be conducted before ensuring that the signals are properly received.

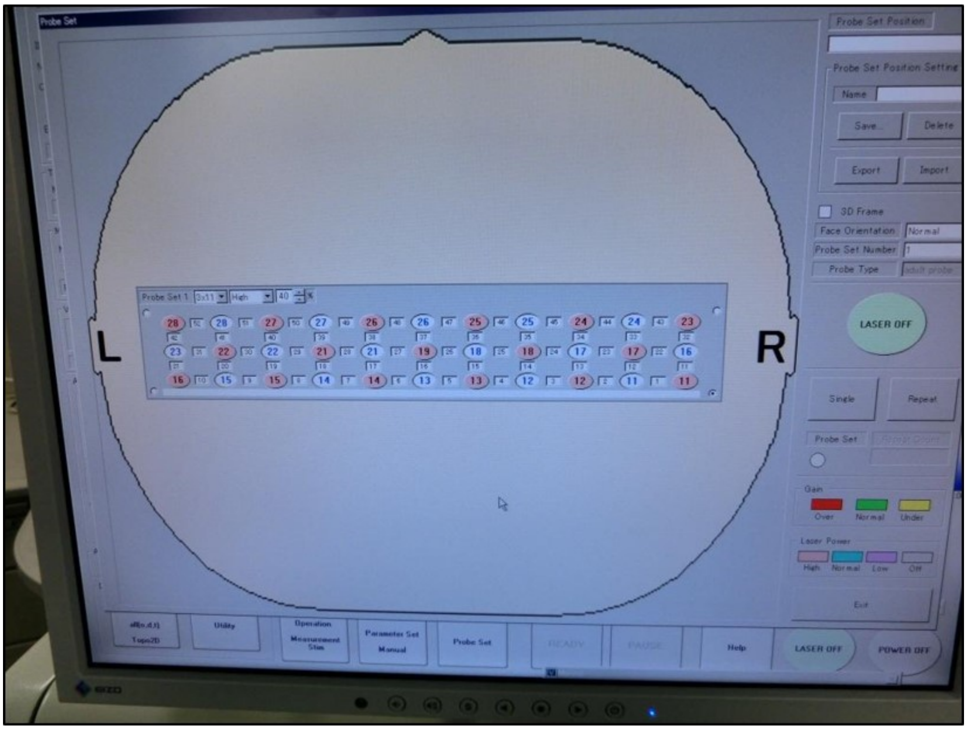
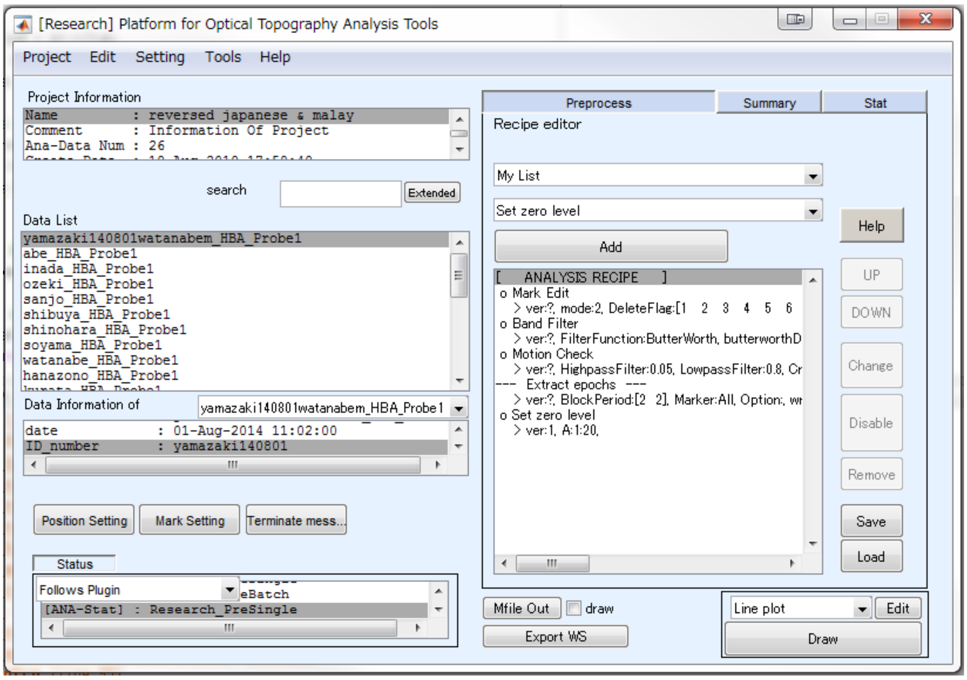


FIGURE 4.9: Confirmation screen of NIRS ETG-4000 probe signal check

The subjects were given instructions to listen to the recorded language sounds with their head being attached to NIRS while answering the questionnaire. Based on the language sounds they listened in the recording, they were required to pick an emotion, out of five choices, that best represents by the language sounds. The questionnaire format was identical to that in the verification test as Figure 4.3 shown in section 4.2.1. In the experiment, relative changes in Hb concentrations of each subjects' brains were measured and recorded by using the NIRS while the subjects were listening to the recording and answering the questionnaire throughout the experiment. The experiment was recorded with a video camera to synchronize the timing of language sounds listening with the timing of the NIRS measurement. For each subject, we measured the Hb concentrations from the moment the language sounds began to the moment it ended.

4.2.4 Data analysis

The oxy-Hb concentration changes in subjects' brains recorded during the experiment were averaged. The average NIRS signal value then will be compared and t-test statistical analysis will be performed on the average NIRS signal value to determine any significant differences. Furthermore, the recorded oxy-Hb concentration changes will be plotted by using the Platform of Optical Topography Analysis Tools (POTATo). A POTATo is an integrated analytical environment for fNIRS signals, which is provided by NeU corporation. POTATo is a MATLAB-based software which adapts the analysis framework of exploratory data analysis (EDA) proposed by John W. T., an American statistician in 1977. EDA focuses on the exploration of data characteristics, often with visual methods rather than the conventional hypothesis test and EDA offers more realistic data analysis. POTATo supports EDA by equipping various graphs for data visualization [53].



```
Name          : reversed japanese & malay
Comment       : Information Of Project
Ana-Data Num  : 26
```

```
yamazaki140801watanabem_HBA_Probe1
abe_HBA_Probe1
inada_HBA_Probe1
ozeki_HBA_Probe1
sanjo_HBA_Probe1
shibuya_HBA_Probe1
shinohara_HBA_Probe1
soyama_HBA_Probe1
watanabe_HBA_Probe1
hanazono_HBA_Probe1
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Data Information of: yamazaki140801watanabem_HBA_Probe1

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date            : 01-Aug-2014 11:02:00
ID_number       : yamazaki140801
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Follows Plugin

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eBatch
[ANA-Stat]  : Research_PreSingle
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My List

Set zero level

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[    ANALYSIS RECIPE    ]
 o Mark Edit
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Figure 4.10: POTATo (MATLAB based software)

Figure 4.10 shows the interface of the POTATo software. The NIRS signal usually contains a lot of biological noises because of the human brain, which is very complex and reacts easily even with a small stimulus. To obtain a better signal, it is necessary to remove the noises. Therefore, by using POTATo software, baseline processing was applied to clarify the change of reaction between before and after a task.

As shown in Figure 4.11, the average value of oxy-Hb concentration changes 'before' was defined as a baseline. Then the average value was subtracted from the value of oxy-Hb concentration changes 'task'. This procedure was applied for all phases and all of the channels to normalize NIRS signals and remove biological fluctuations. Besides, this process was also used as a basis for the averaging processing as shown in Figure 4.12. By averaging a few numbers of the same tasks, the data can be more clarified. In this study, the values of oxy-Hb concentration changes were added based on the task frequency on each background colour to calculate their value.

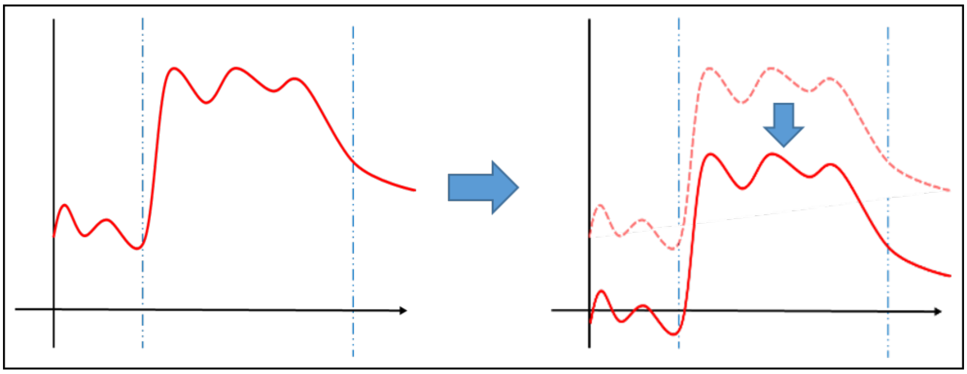


Figure 4.11: Baseline processing

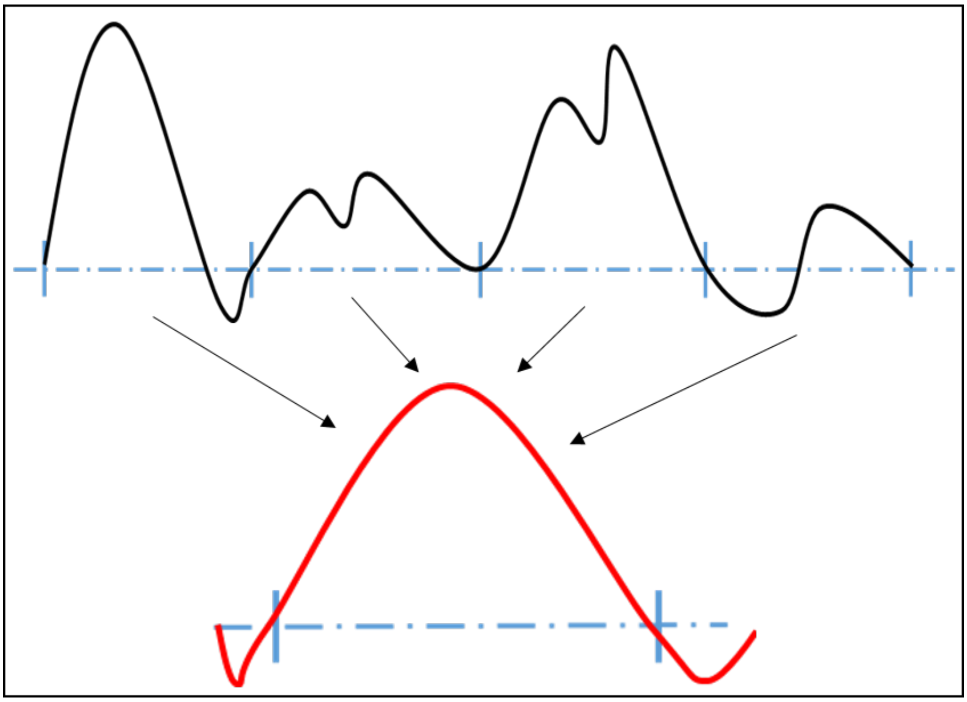


Figure 4.12: Averaging processing

4.3 Malay language sound with five emotions

4.3.1 Language sound sample production

We recorded five sets Malay sentences to compare emotionally neutral and emotionally charged for each language sound. Each set was repeated twice, without and with emotional intonation. We used sentences without obvious emotional connotations to examine the influence of emotional intonation instead of semantic content. In addition, we only recorded 4[s] length of each sentence in order to focus more on emotional effect instead of the sentence itself. Figure 4.13 shows the sample of Malay sentences and Figure 4.14 shows its English translation.


"Saya nak pergi makan."

Figure 4.13: Sample of Malay sentence recording

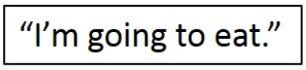

"I'm going to eat."

Figure 4.14: Sample of Malay sentence recording in English translation

4.3.2 Language sound sample verification

A verification test was conducted on the Malay sentences to confirm that each sound conveyed the intended emotion to Japanese individuals unfamiliar with Malay language sounds. We had 44 subjects (37 males, 7 females) listened to the recording sounds and were asked to answer a questionnaire as discussed in section 4.2. The questionnaire answered were then analysed. Figure 4.15 shows the result obtained from the questionnaire. Most of the participants identified the intended emotions correctly and clear enough, and from this result, we judged that the sounds with five emotions and the questionnaire were suitable and could be used for the experiment.

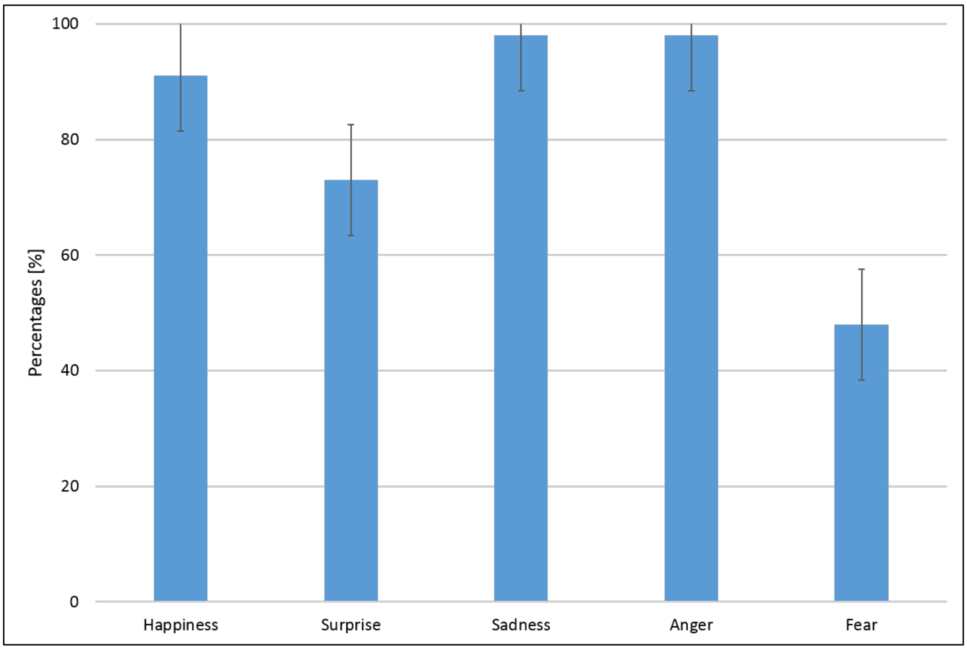


FIGURE 4.15: Verification test results of Malay language sound

4.3.3 Brain activity observation

This procedure mostly had been discussed in section 4.2 Experimentation. For Malay language sound, we had 27 subjects (23 males. 4 females) participated in the experiment. The subjects were instructed to perform the task while having their head with the NIRS on for the measurement. Figure 4.16 presents a block process for the experiment. The NIRS measurement was conducted throughout the process.

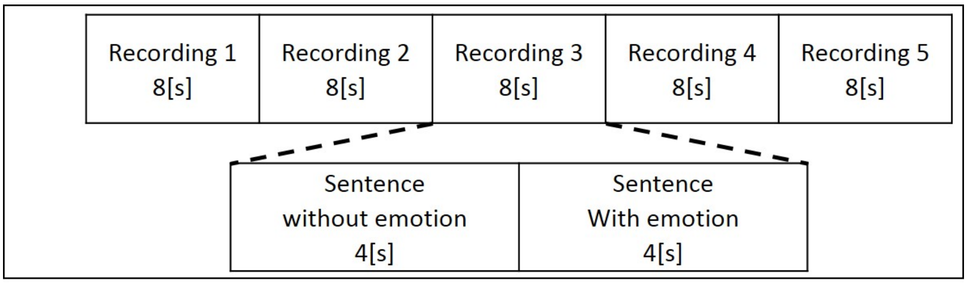


FIGURE 4.16: Block process for the experiment

4.3.4 Results

For all 27 subjects, the oxy-Hb concentration changes were measured every 0.1[s] with the NIRS system and were averaged for both emotionally neutral and emotionally toned sounds. These values are referred to as average NIRS signal values. However, only the measured data from 26 subjects will be analysed for each channel. This is because one of the subject's data was broken and could not be recovered. Therefore, the broken data will not be included in the analysis. The average NIRS signal values have been averaged for both sounds without and with emotions presence of the language areas.

The corresponded channels for language areas are CH 11, CH 17, CH 22, CH 29, CH 30, CH 31, Ch 32, and CH 38. To compare which one that activated the language areas of the brain, we analysed the average NIRS signal values by using t-test statistical analysis ($\alpha = 0.05$) for these channels. The overall t-test statistical analysis result for sounds without emotions and sounds with emotions was shown in Table 4.1.

Table 4.1: NIRS signal values for language areas t-test statistical analysis for sounds without emotions and sounds with emotions ($\alpha = 0.05$)

Malay language sounds	Mean	Variance	t	p
Without emotions	-0.057	0.0005	1.7125	0.081
With emotions	-0.0754	0.0006		

Table 4.1 shows that the t-test statistical analysis stated that there is no significant difference between both sounds without and with emotions presence. Then, we further analysed the activated channel data for each emotion since we used five different emotions (happiness, surprised, sadness, anger, fear) in this experiment. Table 4.2 shows each emotion t-test statistical analysis ($\alpha = 0.05$) of CH30 which corresponded to BA22 for sounds without and with emotions presence.

TABLE 4.2: NIRS signal values for each emotion t-test statistical analysis of CH30 for sounds without emotions and sounds with emotions (α= 0.05)

Emotion	Presence of emotion	Mean	Variance	t	p
Happiness	Without emotion	0.684	48.5758	0.3895	0.3485
	With emotion	0.5663	50.4552		
Surprised	Without emotion	0.5506	47.0782	-0.1852	0.4266
	With emotion	0.603	51.3833		
Sadness	Without emotion	0.6749	43.7145	0.8506	0.1976
	With emotion	0.4243	48.4696		
Anger	Without emotion	0.9429	58.6667	0.8787	0.1899
	With emotion	0.6814	44.8243		
Fear	Without emotion	0.7746	47.4267	-1.055	0.1458
	With emotion	1.0487	67.9328		

Table 4.2 also stated that the t-test statistical analysis expressed no any significant differences for the NIRS signal values of sounds without all emotions presence compared to those with respective emotions. Next, the graph for oxy-Hb concentration changes of CH 30 for emotionally neutral sounds and emotionally toned sounds plotted by using POTATo software is shown in Figure 4.17 and Figure 4.18 respectively. The plot expressed no any obvious different on oxy-Hb concentration changes when subjects listened to emotionally neutral sounds compared to emotionally toned sounds.

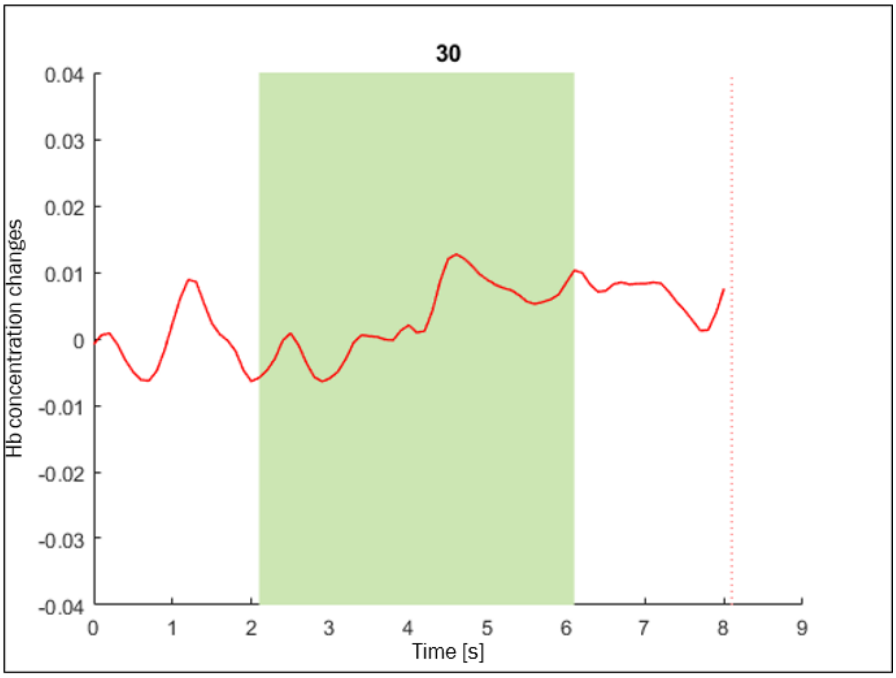


Figure 4.17: Emotionally neutral sounds plot for CH 30

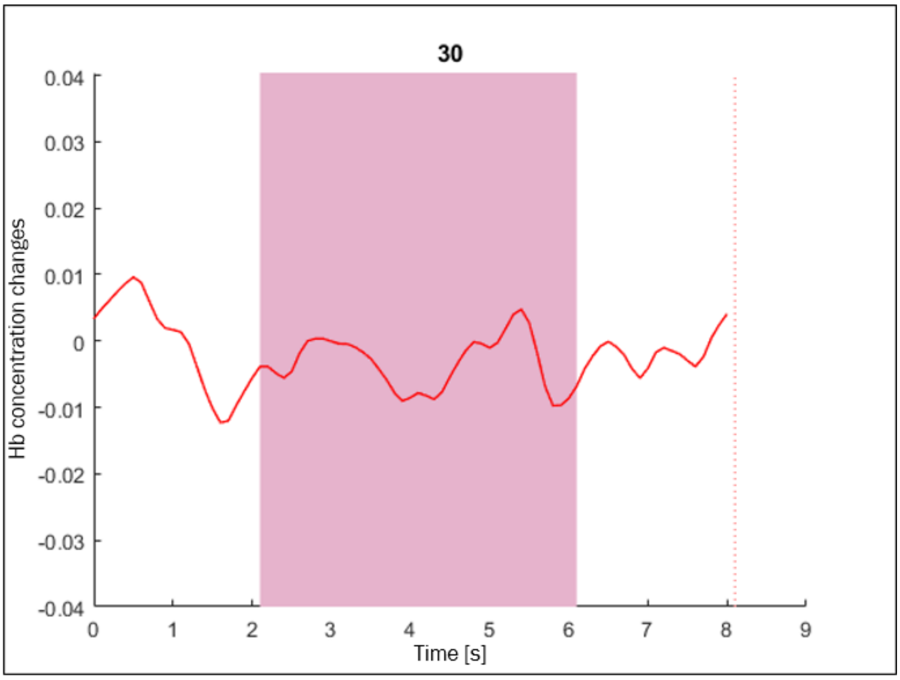


FIGURE 4.18: Emotionally toned sounds plot for CH 30

4.4 Reversed Japanese language sound with five emotions

4.4.1 Language sound sample production

As Malay language sounds, we recorded as well five sets of Japanese sentences. The Japanese sentences were reversed in the recording, making a non-understandable sound despite the language being subjects' native language. This was done to preserve the neutrality (the meaning of the sentence does not carry any emotional load) of the sentence as it is crucial to this experiment. A similar technique was used to investigate the effects of familiar language sounds on the brain functions of infants using NIRS [54]. Each sound was repeated twice, without and with emotional intonation. In addition, we only recorded 4[s] length of each sentence in order to focus more on emotional effect instead of the sentence itself. Figure 4.20 shows the sample of Japanese sentences and its English translation was shown as Figure 4.14 in section 4.3.1.

“あかい”
akai – iaka

FIGURE 4.19: Reversed concept of the sentence

“私は食べに行きたいです。”

FIGURE 4.20: Sample of reversed Japanese sentence recording

4.4.2 Language sound sample verification

We had the same number of subjects as the Malay language sounds verification test, which was 44 subjects (37 males, 7 females) participated in the reversed Japanese language sounds verification test. The questionnaire answered were analysed. Figure 4.21 shows the result obtained from the questionnaire. Most of the participants identified the intended emotions correctly and clear enough, and from this result, we judged that the reversed Japanese sounds with five emotions and the questionnaire were suitable and could be used for the experiment.

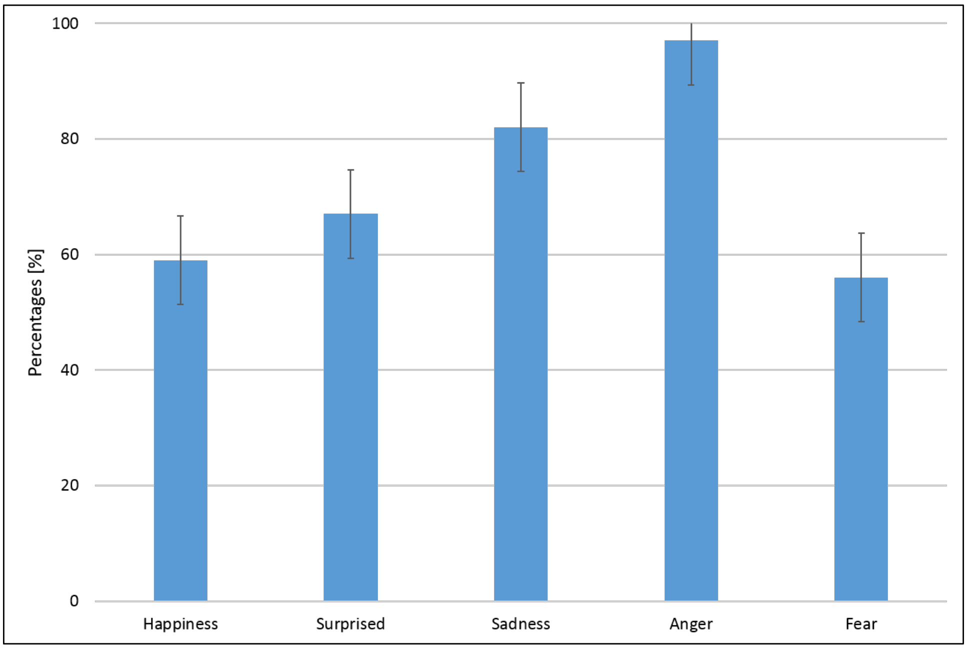


FIGURE 4.21: Verification test results of reversed Japanese language sound

4.4.3 Brain activity observation

Experimentation mostly had been discussed in section 4.2. As well as Malay language sound, we also had 27 subjects (23 males. 4 females) participated in the reversed Japanese language sounds experiment. The subjects were instructed to perform the task while having their head with the NIRS on for the measurement. The block process of the experiment is shown in Figure 4.16 in section 4.3.3. The NIRS measurement was conducted throughout the process.

4.4.4 Results

As well as section 4.3.4, for all 27 subjects, the oxy-Hb concentration changes also were measured every 0.1[s] with the NIRS system and were averaged for both emotionally neutral and emotionally toned sounds. These values are referred to as average NIRS signal values. However, only the measured data from 26 subjects will be analysed for each channel. This is because one of the subject's data was broken and could not be recovered. Therefore, the broken data will not be included in the analysis. The average NIRS signal values have been averaged for both sounds without and with emotions presence.

The corresponded channels for language areas are CH 11, CH 17, CH 22, CH 29, CH 30, CH 31, Ch 32, and CH 38. To compare which one that activated the language areas of the brain, we analysed the average NIRS signal values by using t-test statistical analysis ($\alpha = 0.05$) for these channels. The overall t-test statistical analysis result for sounds without emotions and sounds with emotions was shown in Table 4.3.

Table 4.3: NIRS signal values for language areas t-test statistical analysis for sounds without emotions and sounds with emotions ($\alpha = 0.05$)

Reversed Japanese language sounds	Mean	Variance	t	p
Without emotions	0.1118	0.0033	1.1035	0.1659
With emotions	0.0586	0.0065		

Table 4.3 shows that there is no significant difference between both sounds without and with emotions presence. Then, we further analysed the activated channel data for each emotion since we used five different emotions (happiness, surprised, sadness, anger, fear) in this experiment. Table 4.4 shows each emotion t-test statistical analysis ($\alpha = 0.05$) of CH30 which corresponded to BA22 for sounds without and with emotions presence.

TABLE 4.4: NIRS signal values for each emotion t-test statistical analysis of CH30 for sounds without emotions and sounds with emotions ($\alpha = 0.05$)

Emotion	Presence of emotion	Mean	Variance	t	p
Happiness	Without emotion	0.645	34.2314	-0.0392	0.4844
	With emotion	0.655	50.5566		
Surprised	Without emotion	1.153*	69.2912	1.6819	0.0464
	With emotion	0.5612	39.5783		
Sadness	Without emotion	0.8669	51.3754	-0.2891	0.3863
	With emotion	0.9619	62.4985		
Anger	Without emotion	0.3753	41.4246	-1.6176	0.053
	With emotion	0.8103	44.3765		
Fear	Without emotion	0.9221*	50.6561	2.099	0.018
	With emotion	0.2524	41.5134		

*$p<0.05$

Table 4.4 stated that sounds without surprised and fear emotions presence have higher NIRS signal value compared to those without respective emotions. Furthermore, the t-test statistical analysis for those emotions perform significant differences for the NIRS signal value. From these results, we suggested that higher NIRS signal values have been observed when subjects listened to the reversed Japanese sounds without emotions compared to the sounds with emotions presence.

The graph for oxy-Hb concentration changes of CH 30 for emotionally neutral sounds and emotionally toned sounds plotted by using POTATo software is shown in Figure 4.21 and Figure 4.22 respectively. Overall, it may be said that reversed Japanese sounds without emotions displayed a higher rate of changes in oxy-Hb in comparison to reversed Japanese sentences with the presence of emotions.

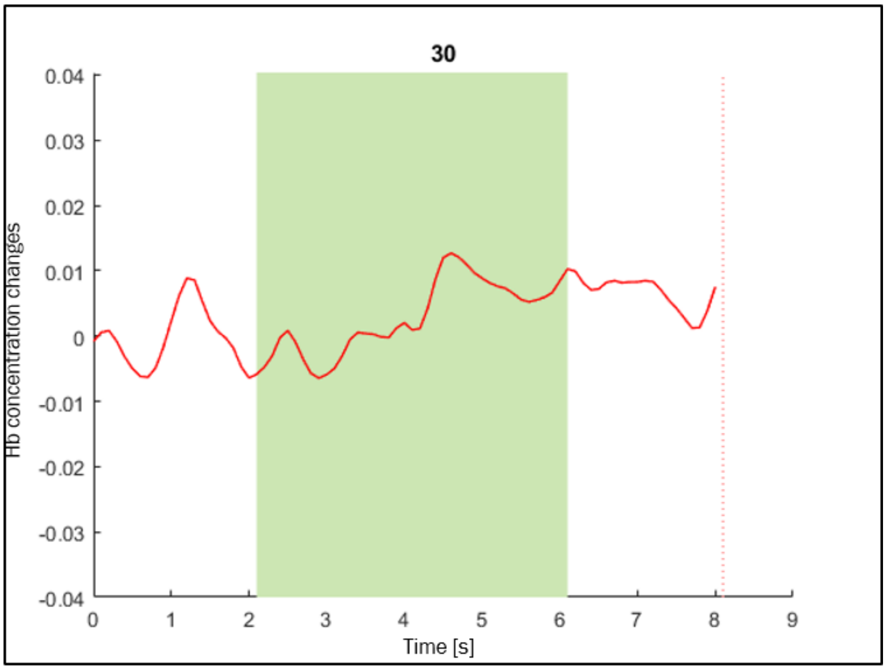


Figure 4.22: Emotionally neutral sounds plot for CH 30

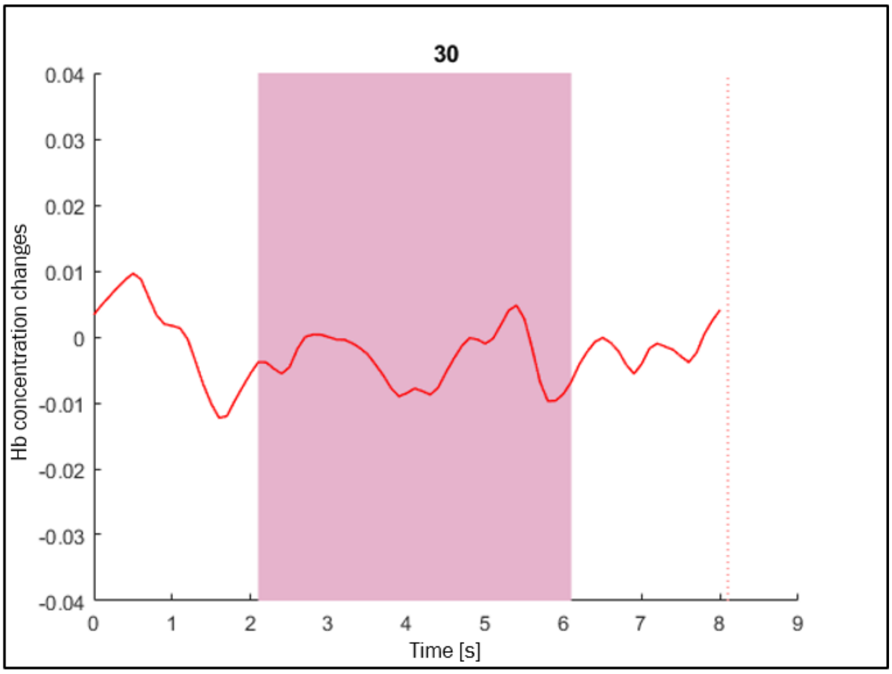


FIGURE 4.23: Emotionally toned sounds plot for CH 30

4.5 Reversed Japanese language sound with three emotions

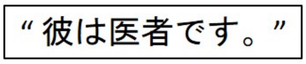
The reversed Japanese language sound with three emotions was extended from reversed Japanese language sound with five emotions. We decided to make the task more difficult compared to language sound with five emotions. We believed that brain activity will express better results in details if we conduct the task at a more challenging level.

4.5.1 Language sound sample production

Unlike reversed Japanese language sounds with five emotions, we recorded five Japanese sentences. Each sentence was recorded four times—without emotion intonation, happiness, sadness, and anger emotions presence. All the recorded Japanese sentences were reversed, making a non-understandable sound despite the language being subjects' native language. This was done to preserve the neutrality (the meaning of the sentence does not carry any emotional load) of the sentence as it is crucial to this experiment too. In addition, we only recorded 2[s] length of each sound in order to focus more on emotional effect instead of the sentence itself. The reversed concept is the same as reversed Japanese language sound with five emotions as shown in Figure 4.19 from section 4.4.1.

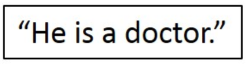
4.5.2 Language sound sample verification

To gauge whether each reversed language sound with emotion is perceived as a sound with the intended emotion, we conducted a verification test with 30 Japanese speakers whose ages ranged from 18 to 22 years. The subjects listened to 15 recorded language sounds (five different sentences with three emotions) and then chose one of the five emotions; happiness, sadness, anger, fear, or surprise as the emotion expressed by each sound in the recording. Figure 4.24 shows the sample of Japanese sentences and Figure 4.25 shows its English translation. The block process of the verification test shows in Figure 4.26.



" 彼は医者です。"

Figure 4.24: Sample of reversed Japanese sentence with three emotions recording



"He is a doctor."

Figure 4.25: Sample of reversed Japanese sentence with three emotions recording in English translation

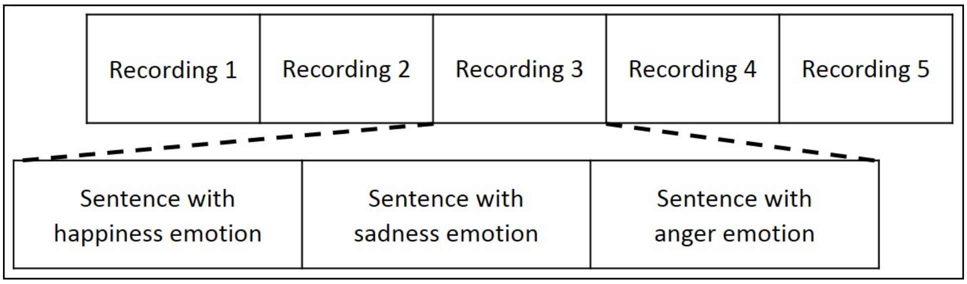


FIGURE 4.26: Block process of the verification test

The questionnaire answered were analysed. Table 4.5 shows the result obtained from the questionnaire. The percentages of subjects who answered correctly varied from 26% to 100%. Most of the students confused the happiness with surprised. The recording of sounds with sadness emotion, however, was often mistaken as sounds expressed with fear. As for sounds delivered with anger emotion, they were frequently confounded with either surprised and fear emotions.

Generally, sounds conveyed with anger emotion have higher validity percentage compared to happiness and sadness emotions. For our purposes, we regarded language sounds with more than 70% correct answers as ones that convey emotions correctly and clear enough, and decided to use three sets of reversed sentences as sound samples for our NIRS brain function experiment.

Table 4.5: Verification test results

Recording	Emotion	Percentage (%)
1	Happiness	70.00
1	Sadness	93.33
1	Anger	100.00
2	Happiness	26.67
2	Sadness	83.33
2	Anger	93.33
3	Happiness	70.00
3	Sadness	83.33
3	Anger	93.33
4	Happiness	36.67
4	Sadness	60.00
4	Anger	90.00
5	Happiness	70.00
5	Sadness	80.00
5	Anger	90.00

4.5.3 Brain activity observation

Experimentation mostly had been discussed in section 4.2. For reversed Japanese language sound with three emotions, we had 21 subjects (19 males, 2 females) participated in the experiment. Three sounds expressed with happiness, sadness, and anger respectively were selected from the verification test. The same sounds without any emotional effects also have been prepared which make up a total of six recordings. The subjects were instructed to perform the task while having their head with the NIRS on for the measurement.

The NIRS measurement was conducted throughout the process and the block process of the experiment was displayed in Figure 4.27. After each subject finished listening to each of the sound recordings, they were asked to choose the emotion expressed by the language sound from the questionnaire. An example of the questionnaire used in the study is shown in Figure 4.28 and its English translation is shown in Figure 4.29.

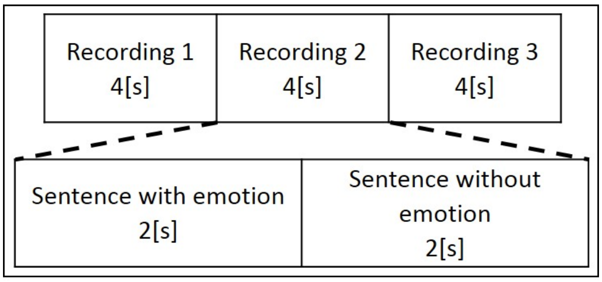
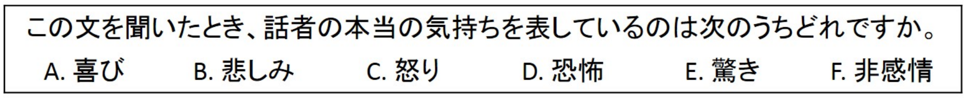


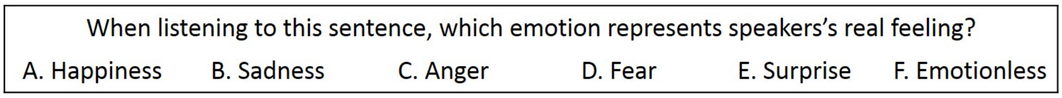
FIGURE 4.27: Block process of reversed Japanese language sound with three emotions experiment



この文を聞いたとき、話者の本当の気持ちを表しているのは次のうちどれですか。

A. 喜び　B. 悲しみ　C. 怒り　D. 恐怖　E. 驚き　F. 非感情

FIGURE 4.28: Sample of questionnaire for reversed Japanese language sound with three emotions experiment



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

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

FIGURE 4.29: English translation of questionnaire for reversed Japanese language sound with three emotions experiment

4.5.4 Results

As well as section 4.4.4, for all 21 subjects, the oxy-Hb concentration changes also were measured every 0.1[s] with the NIRS system and were averaged for both emotionally toned and emotionally neutral sounds. These values are referred to as average NIRS signal values. The average NIRS signal values have been averaged for both sounds with and without emotions presence. The corresponded channels for language areas are CH 11, CH 17, CH 22, CH 29, CH 30, CH 31, Ch 32, and CH 38. To compare which one that activated the language areas of the brain, we analysed the average NIRS signal values by using t-test statistical analysis (α= 0.05) for these channels. The overall t-test statistical analysis result for sounds with emotions and sounds without emotions was shown in Table 4.6.

TABLE 4.6: NIRS signal values for language areas t-test statistical analysis for sounds with emotions and sounds without emotions (α= 0.05)

Reversed Japanese language sounds	Mean	Variance	t	p
With emotions	0.0404*	0.0012	4.1881	0.0263
Without emotions	0.0276	0.0009		

*p<0.05

Table 4.6 shows that average NIRS signal value for sounds with emotions is higher than those without emotions for language areas of the brain that were covered by the NIRS probes. Furthermore, the t-test statistical analysis stated a significant difference ($p<0.05$) between both sounds with and without emotions presence. Then, we further analysed the data for each emotion since we used three different emotions (happiness, sadness, anger) in this experiment. Table 4.7 shows each emotion t-test statistical analysis ($\alpha= 0.05$) of CH38 which corresponded to BA45 for sounds with and without emotions presence.

Table 4.7: NIRS signal values for each emotion t-test statistical analysis of CH38 for sounds with emotions and sounds without emotions ($\alpha= 0.05$)

Emotion	Presence of emotion	Mean	Variance	t	p
Happiness	With emotion	0.0645***	7.9E-05	5.6778	7.4E-06
	Without emotion	0.0452	0.0002		
Sadness	With emotion	0.2218***	0.0001	16.5703	1.9E-13
	Without emotion	0.1633	0.0002		
Anger	With emotion	0.1398	0.0003	1.3335	0.0987
	Without emotion	0.1336	0.0002		

***$p<0.001$

Table 4.7 stated that sounds with happiness, sadness, and anger emotions presence have higher NIRS signal value compared to those without respective emotions. Furthermore, the t-test statistical analysis for each emotion performs significant differences (p<0.001) for the NIRS signal value. From these results, we suggested that higher NIRS signal values have been observed when subjects listened to the reversed Japanese sounds with emotions compared to the sounds without emotions presence.

The graph for oxy-Hb concentration changes of CH 38 for emotionally toned sounds and emotionally neutral sounds plotted by using POTATo software is shown in Figure 4.30 and Figure 4.31 respectively. Overall, reversed Japanese sounds with three emotions show more explicit results than reversed Japanese sounds with five emotions and it may be said that reversed Japanese sounds with emotions displayed a higher rate of changes in oxy-Hb in comparison to reversed Japanese sounds without the presence of emotions.

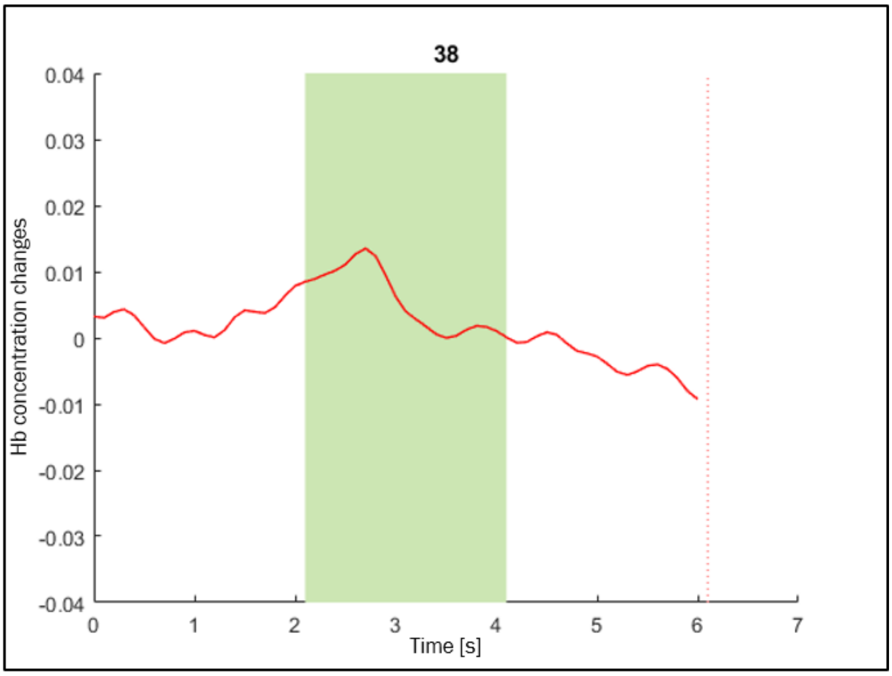


Figure 4.30: Emotionally toned sounds plot for CH 38

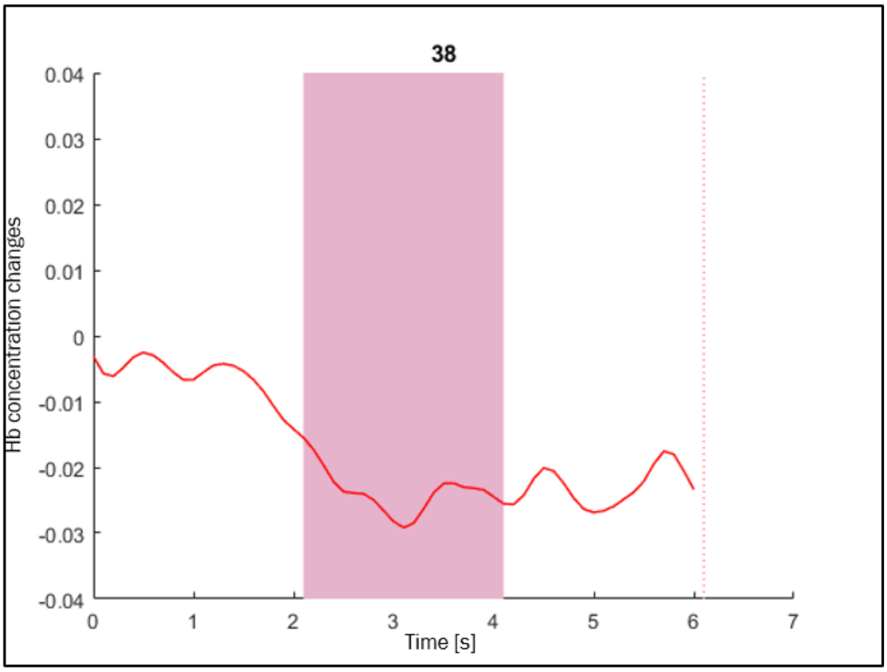


FIGURE 4.31: Emotionally neutral sounds plot for CH 38

4.6 Discussion

In this study, relative changes of blood Haemoglobin (Hb) concentration in the brain were observed by using near-infrared spectroscopy (NIRS) system to see the brain function activities of the subjects while they were listening to the sounds that they did not understand, with and without emotions. The oxygenated Hb (oxy-Hb) concentration changes in subjects' brains recorded were mapped onto 2D topography images. The images were analysed concerning the functions of brain regions.

Figure 4.29 and Figure 4.30 show 2D topography images of brain activity that were constructed from NIRS measurement. The figures show typical examples of Hb concentration images created from the Hb measurements while the experiment was conducted. The red region on the topographic results represents higher concentration changes in blood Hb, whereas the blue region represents lower concentration changes, i.e. the red region shows high brain activity and the blue region shows less brain activity or a calm state.

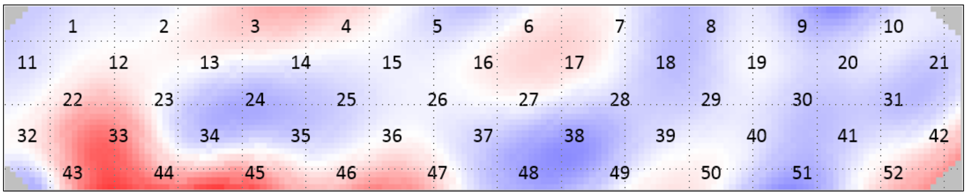


FIGURE 4.32: Typical 2D topography images of brain activity with channel labelled

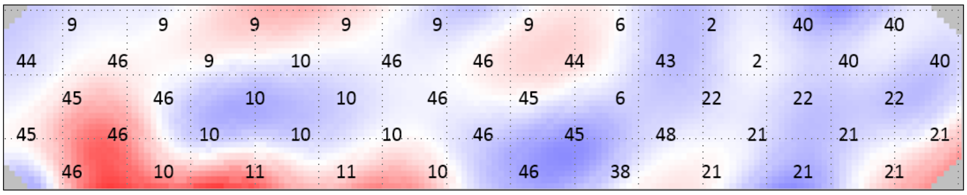


FIGURE 4.33: Typical 2D topography images of brain activity with corresponding Brodmann areas (BA) labelled

4.6.1 Malay language sound with five emotions

The results from the NIRS measurement demonstrate that Malay language sounds did not expressed any obvious different on the rate of changes in oxy-Hb at language areas when comparing Malay language sounds with and without the presence of emotions. However, the results from the subjects listening to the sounds without emotions showed that Channel (CH) 30 which roughly correspond to BA 22 tended to experience higher levels of change in Hb concentration. BA 22 (Wernicke's area) is important in processing complex sound [55]. It also participates together with BA 21, which believed to play a part in auditory processing and language such as selective processing of speech [55][56].

On the other hand, a part of this experiment's region of interests (ROI) which correspond to Broca's area relative to BA 44 and 45 showed less activation in both Malay language sounds with and without emotions. Since Malay language sound is the new sound for the subjects and Broca's area seems to be involved in grammatical processing, the subjects could not pick up any meaning from Malay language sound which causes less activation at Broca's area [57].

Besides, most of the channels which roughly correspond to BA 9 and 10, have higher oxy-Hb concentration changes while subjects listened to the emotionally toned Malay language sounds. BA 9 and 10 are the part of the front polar region in the frontal cortex and have significant participation in memory, especially working memory including attention to human voices and emotional stimuli processing [58][59].

To sum up, the findings suggest that although Japanese subjects never heard the Malay language sounds before, the subjects could recognize it as a language sound when there are no emotions present in the sound. Thus, we believed that sentences with emotions are might not suitable for learning a new language in communication as difficulties with auditory encoding may impede language acquisition [60]. These, contradict with Mazur *et al.*'s finding that suggests the emotions might be an effective way for language learning [61]. Subjects' brain gave too much attention to the emotion rather than to the language. On the contrary, this indicates that the emotional content can affect the attention because emotional stimuli are likely to "grab" attention [62]. Thus, we deduced that the emotions in the Malay language sound were successfully conveyed when the subjects listened to the emotionally toned sounds. Ezster argue that listeners can detect and recognise emotional states from speakers with a different language and cultural background as the process involved emotional stimuli [63].

4.6.2 Reversed Japanese language sound with five emotions

The results from NIRS measurement show that reversed Japanese language sounds without emotions displayed a higher rate of changes in oxy-Hb at language areas in comparison to reversed Japanese language sounds with the presence of emotions. The results show the same tendency as Malay language sound. However, reversed Japanese language sound activate language areas more than Malay language sound. We believed that the results showed the same tendency because the experiment for reversed Japanese language sound was conducted right after the experiment for Malay language sound. The effects from Malay language sound experiment might affect the experiment results of reversed Japanese language sound. Furthermore, the results from the subjects listening to the sounds with emotions showed that CH 30 which roughly correspond to BA 22 tended to experience higher levels of change in Hb concentration. As discussed in section 4.6.1, BA 22 is corresponded to Wernicke's area which is for language input.

On the other hand, a part of this experiment's ROI which correspond to Broca's area relative to BA 44 and 45 showed less activation in reversed Japanese language sounds with and without emotions. These language areas of the brain are commonly used to interpret grammar and vocabulary. Since reversed Japanese language sounds were used in this experiment, we suspect that the subjects who are all native speakers of Japanese were not able to pick up the meaning of the sentences, instead, the familiarity of the sound with emotions activate the auditory processing exceptionally [55][56][57]. This is because the presence of emotion modulates auditory processing [64].

Besides, we found out that BA 10 which located at the frontal areas of the brain that are associated with working memory were highly activated when the subjects listened to all five sounds with emotion. Prefrontal cortex such as BA 10 participates in working memory, which is a limited capacity system required for the ability to maintain and manipulate information over short periods in the service of other cognitive tasks.

The vast majority of studies examining the link between emotion and working memory have focused on emotional state. Most studies have found that mood induction results in a change in cognitive task performance [62]. Even though the sentences have been reversed, BA 10 which also involved in emotions processing of subjects' brain also highly activated [65]. As mentioned in section 4.6.1, listeners can recognise emotions from speakers in any language [63]. Even though this study reversed the emotional sentences to filter out the effect of sentence meaning, the familiarity of the sound encouraged the accuracy of emotion detection [66]. The results also stated that subjects' brain areas related to working memory and emotion processing activated the most while listening to the sound with the presence of emotion. This suggests that sentences spoken with emotional load may be slightly preferable to sentences without emotions for sounds recognition of familiar language and maintaining information over short periods.

4.6.3 Reversed Japanese language sound with three emotions

Overall, reversed Japanese sounds with three emotions show more explicit results than reversed Japanese sounds with five emotions and it may be said that reversed Japanese sounds with emotions displayed a higher rate of changes in oxy-Hb atlanguage areas in comparison to reversed Japanese sounds without the presence of emotions. The results from the subjects listening to the sounds with emotions showed that CH 38 which roughly correspond to BA 45 tended to experience higher levels of change in Hb concentration.

We observed higher activation at language areas (Broca's area) which related to BA 44 and 45. This is because the emotions used are much more simple and clearer that significantly enhance the brain activities in that area. The linguistic areas used emotion expressed in the language sounds like a clue to try to comprehend the sentences. The brain instinctively tried to process the emotions expressed in the language sounds [67][68]. Therefore, the author concluded that sentences spoken with emotional load may be preferable to sentences without emotions for sounds recognition of familiar language and maintaining information over short periods. Besides, if the emotions are successfully conveyed, the language areas also might be activated.

As discussed in section 4.6.2, BA 10 and 46 from the prefrontal cortex are involved in working memory and also emotions processing [65]. Emotions can be recognised easily regardless of language used, particularly when speaker's language and listener's language matched each other [63][66]. This study also suggests that despite the sentences have been reversed, the emotions are successfully conveyed and activated subjects brain.

4.7 Conclusion

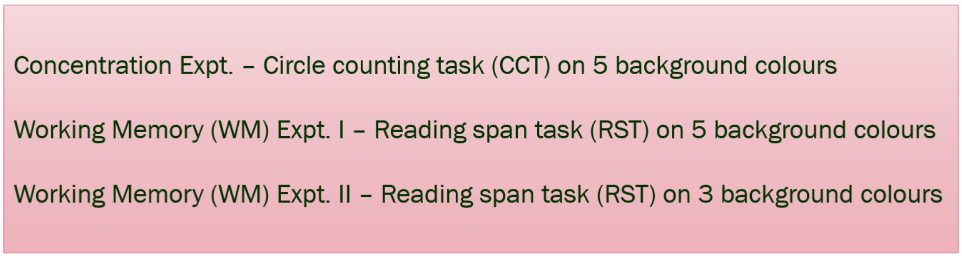
In conclusion, this chapter discussed the effect of emotion in language sounds. Thus, the following points are provided:

- Malay language sounds with five emotions did not show any obvious change at the language areas of subjects' brain. The subjects recognize the Malay language as a language sound better when there is no presence of emotions, since the Malay language is a new language to them. On the other hand, subjects could comprehend the emotions conveyed in Malay sentences, even though they could not understand the meaning of the sentences. We concluded that too much attention on emotion, distract the activation of language areas.
- Reversed Japanese language sounds with five emotions did not activate the language areas of subjects' brain. As well as Malay language sounds, the subjects also could recognize the emotions conveyed even the sentences have been reversed that left an impact on working memory. Even though, reversed Japanese language sound activated language areas more than Malay language sound, we believed that the results of reversed Japanese sound have been affected by Malay language sound. Therefore, we also concluded that too much attention on emotion, distract the activation of language areas.
- Reversed Japanese language sounds with three emotions did activate the language areas subjects' brain. Not only that, working memory and emotion processing of the brain also significantly activated. Since only three emotions have been used for this experiment, more significant results have been revealed. If the emotions are successfully conveyed, the subjects' brain tried to comprehend the meaning of the sentences.

Chapter 5

Cognitive Task on Different Background Colours

In this chapter, the details of the emotion process experiments are discussed. This chapter consists of three different experiments. Each experiment will be discussed in section 5.3, 5.4, and 5.5 respectively in details. However, the methodology applied in the three experiments were almost the same and will be discussed separately in section 5.2.



Concentration Expt. – Circle counting task (CCT) on 5 background colours

Working Memory (WM) Expt. I – Reading span task (RST) on 5 background colours

Working Memory (WM) Expt. II – Reading span task (RST) on 3 background colours

Figure 5.1: Three experiments in Chapter 5

5.1 Cognitive performance and background colour

Tablet computers have been used to enhance people's daily lives and to intensify the cognitive ability of the brain. Many studies have proposed that when people using a tablet computer, the design of a tablet computer screen can give an effect on attention, concentration, and performance of the brain [19]. Several studies also have examined font type and background colour combinations on a computer screen concerning the impact on task performance [15][16]. The purpose of this research is to investigate the effects of screen background colours on the brain functions in order to enhance users' cognitive ability such as working memory and concentration especially for elderly people.

Herein, we examined the performance and brain functions of a subject when completing a task on different background colours of a tablet computer. The authors explored the brain activities of the subjects to observe the differences in the brain regions related to working memory and concentration. The focus was to determine the background colour appropriate for enhancing cognitive abilities and improving performance. As an ageing population is a serious social problem, this study also compared the brain activities of the two groups. By using near-infrared spectroscopy (NIRS), this research will attempt to investigate the activities of the brain when the subjects are exposed to different screen background colours.

The authors hope that the result of this research will contribute to designing effective and comfortable screen backgrounds for people to learn and use Information and Communication Technology (ICT) devices. Besides, the results could assist in determining a suitable method to enhance cognitive ability. Thus, it could contribute to improving the quality of life for people.

5.2 Methodology

There are two main step of the experiment. The first step is cognitive task design. The, it will follow by the brain activity observation. Figure 5.2 shows the step of the experiment for this study.

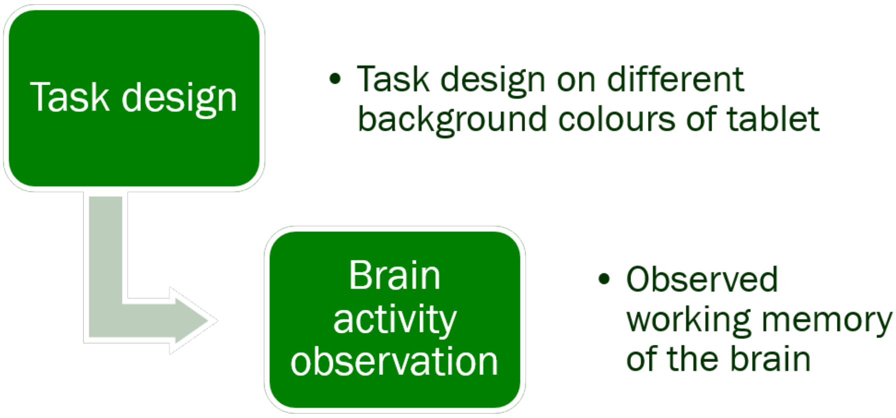


FIGURE 5.2: Procedure step of the experiment

5.2.1 Cognitive task design

All procedures used in this research were approved by the Ethical Committee of Shibaura Institute of Technology. In this study, the black text will be combined with different colours as a screen background. The background colours to be used for the brain training tasks were blue, red, white, yellow, and green. The two brain training tasks were circle counting task (CCT) and reading span task (RST). Both of the tasks will be conducted on a tablet computer. The tablet that we used in this study is Lenovo Yoga 2 with 10.1" of screen size and (1920x1200) pixels of resolutions.

NIRS will be used to measure the change of cerebral blood volume of the subjects during the task. Moreover, we can understand the activated sites of the brain concerning the effects of different background colours by analysing NIRS signals. Table 5.1 shows the characteristics of the colour that will be used in the experiment. Formulas suggested by the World Wide Web Consortium (W3C) were used to calculate these values [69].

TABLE 5.1: Background colours characteristics with black text

Background colour	Hexadecimal code	Brightness difference	Colour difference	Contrast ratio	Relative luminance (%)
White	#FFFFFF	255	765	21	100
Blue	#0000FF	29	255	2.44	7.22
Green	#00FF00	150	255	15.3	71.52
Red	#FF0000	76	255	5.25	21.26
Yellow	#FFFF00	226	510	19.56	92.78

FIGURE 5.3: The tablet computer used in the experiment

CCT is the task where subjects need to count the circle in a time given. The circle will be drawn randomly with other shapes such as star and triangle. CCT requires subjects' attention and concentration. On the other hand, RST is the task where subjects need to read aloud a sentence while memorising the underlined word in the same sentence. RST focuses on the working memory areas of the brain. Figure 5.4 and 5.5 show the sample of CCT and RST prepared on a single background colour of a tablet computer respectively. Both of the brain training tasks will be discussed in details in the section of each experiment.

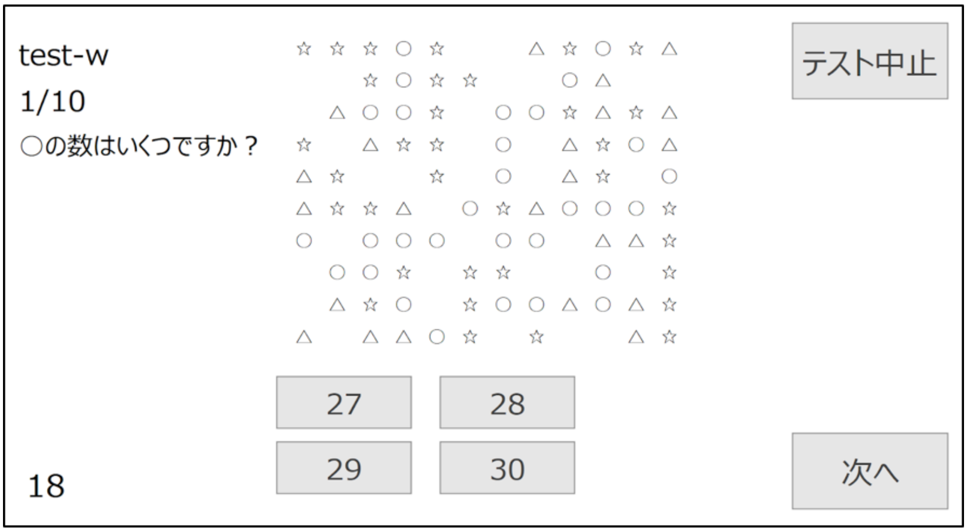


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FIGURE 5.4: The sample of CCT

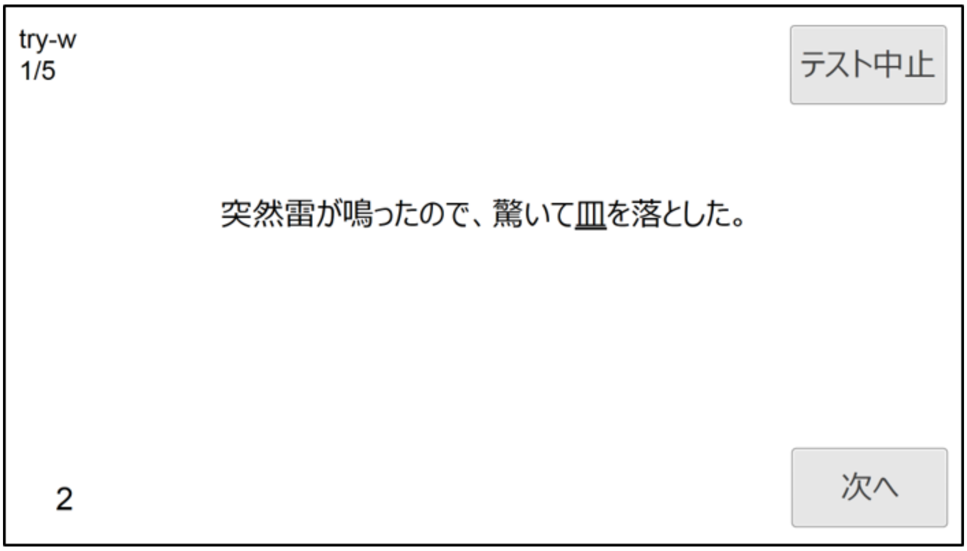

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FIGURE 5.5: The sample of RST

5.2.2 Participants

Healthy two groups of subjects (males and females) were recruited to participate in this study. All the subjects reported no colour vision deficiency at the time of the experiment. The two groups were university students (between 18-26 years old) and elderly people (between 65-81 years old). Both of the subjects groups' first language is Japanese. The subjects were given explanations before undertaking the tasks. Informed consent was obtained from all individual participants involved in the study, with all experiments being carried out at Shibaura Institute of Technology. Completion of all background colours of the tasks required 10-30 minutes. All of them performed the tasks on the tablet computer without any trouble during the experiment.

5.2.3 Experimentation

In this study, we used a NIRS system developed by Hitachi Medical Corporation (WOT-100, 16 channels) to observe and record haemoglobin (Hb) concentration of the brain of every subject in every 0.2[s]. Brain areas activation can be detected by the increments of the values of the oxygenated Hb (oxy-Hb) changes. A built-in (2×6) measurement probes were alternated between irradiation and detection probes. The distances between the irradiation and detection probes (measurement area) are called channels and are 30[mm] apart. The head gear of WOT-100 is shown in Figure 5.6. After the headgear was ready, it was then applied to the subject's head. The channels are covered in the frontal region of the prefrontal cortex. The mounting position of probes and NIRS measurement areas are shown in Figure 5.7. Figures 5.8 shows young and elderly female subjects with optical topography probes applied to their forehead and the position of the headgear.

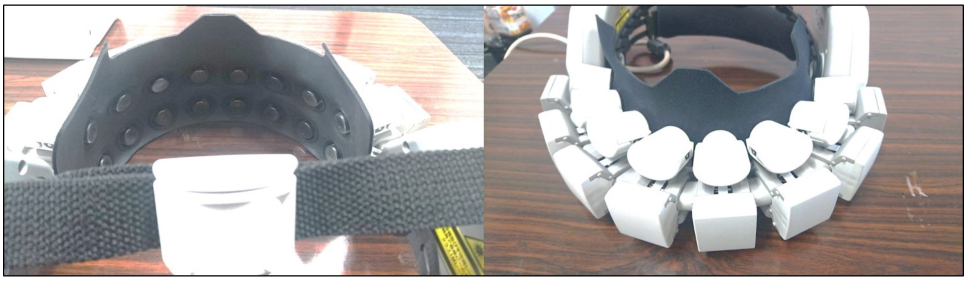


Figure 5.6: WOT-100 headgear

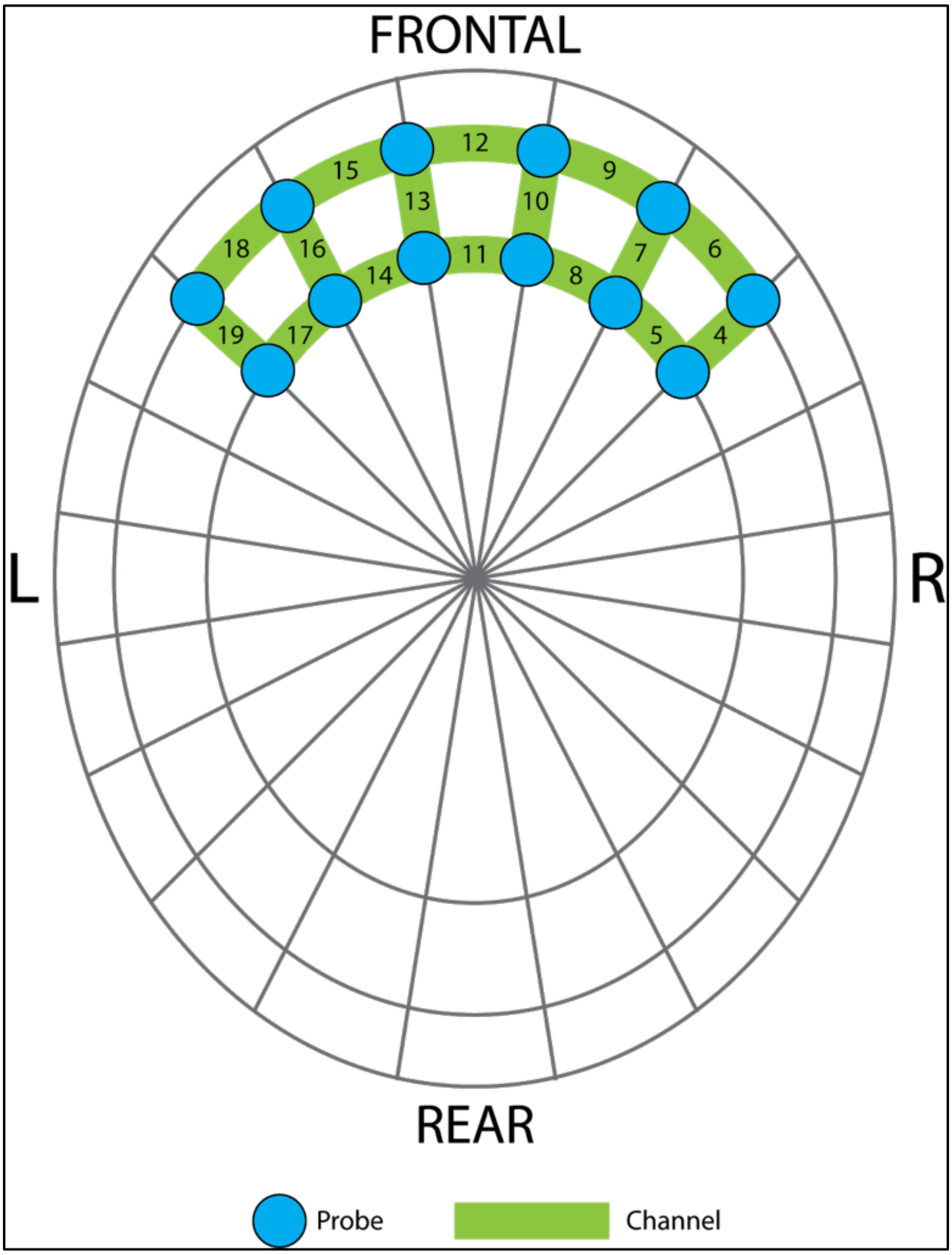


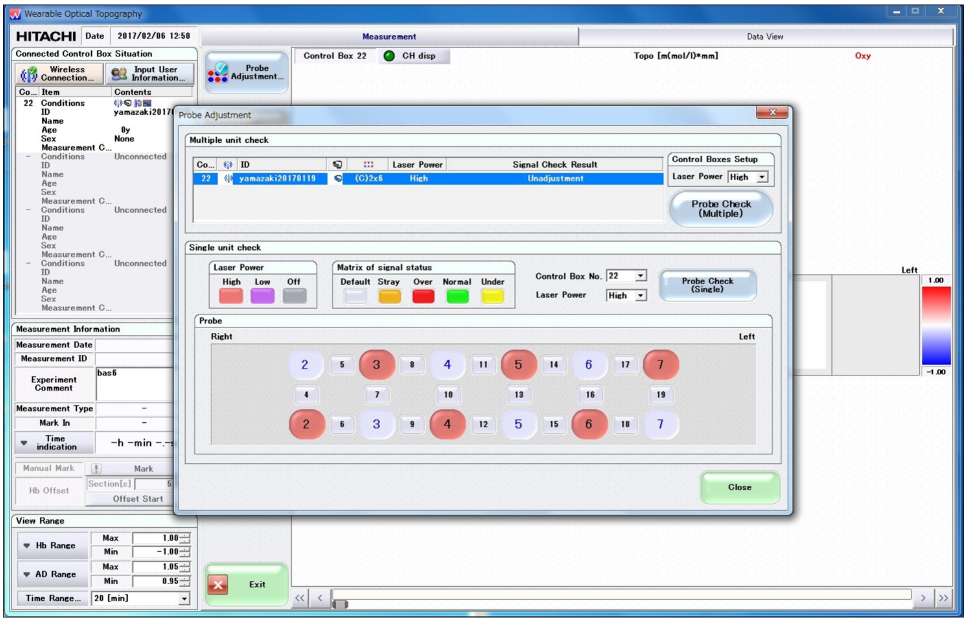
Figure 5.7: Channel mapping of NIRS WOT-100

[redacted]

[redacted]

Figure 5.8: Positions of NIRS WOT-100 probe on the subjects' head

Before starting the experiment, the signals were first tested to confirm whether they were properly acquired and irradiated using the utility provided in the NIRS system, as shown in Figure 5.9. If the signals were not properly received, the head-gear was fixed and positioned once again until all signals were confirmed to be received by all channels. The complications were often due to the amount of subject's hair and the size of the head which can prevent the light radiation to reach the scalp. This experiment must not be conducted before ensuring that the signals are properly received.



Date 2017/02/06 12:50

Control Box 22

Topo [m(mol/l)*mm] Oxy

Control Box No. 22

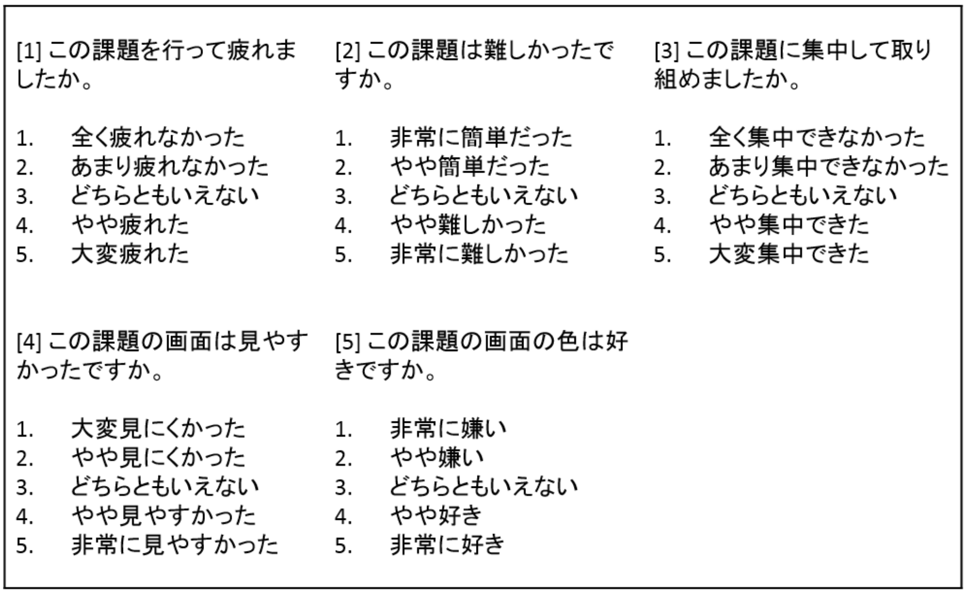
Laser Power High

Co...	ID		Laser Power	Signal Check Result
22	yamazaki20170119	(C)2x6	High	Unadjustment

FIGURE 5.9: Confirmation screen of NIRS WOT-100 probe signal check

The experiment was conducted with two tasks on the tablet computer, which are CCT and RST on different background colours to identify which part of brain functions will show activation. The background colours were white, blue, yellow, red, and green on a black text with random order. The experiment has been conducted one to one which is one subject with one tester. The brains functions of each subject were measured throughout the experiment. The experiment was recorded with a video camera to synchronize the timing of starting the task with the timing of the NIRS measurement.

None of the subjects experienced any difficulties with the tasks. After completing the task for each background colour, the subjects responded to a designated questionnaire to provide feedback about the task and their personal information. The questionnaire asked the subjects to rate their tiredness, readability, difficulty, colour preferences and concentration levels on a five-point Likert scale. The original and its English translation of the questionnaire sample is shown in Figure 5.10 and 5.11 respectively.



[1] この課題を行って疲れましたか。

1. 全く疲れなかった
2. あまり疲れなかった
3. どちらともいえない
4. やや疲れた
5. 大変疲れた

[2] この課題は難しかったですか。

1. 非常に簡単だった
2. やや簡単だった
3. どちらともいえない
4. やや難しかった
5. 非常に難しかった

[3] この課題に集中して取り組めましたか。

1. 全く集中できなかった
2. あまり集中できなかった
3. どちらともいえない
4. やや集中できた
5. 大変集中できた

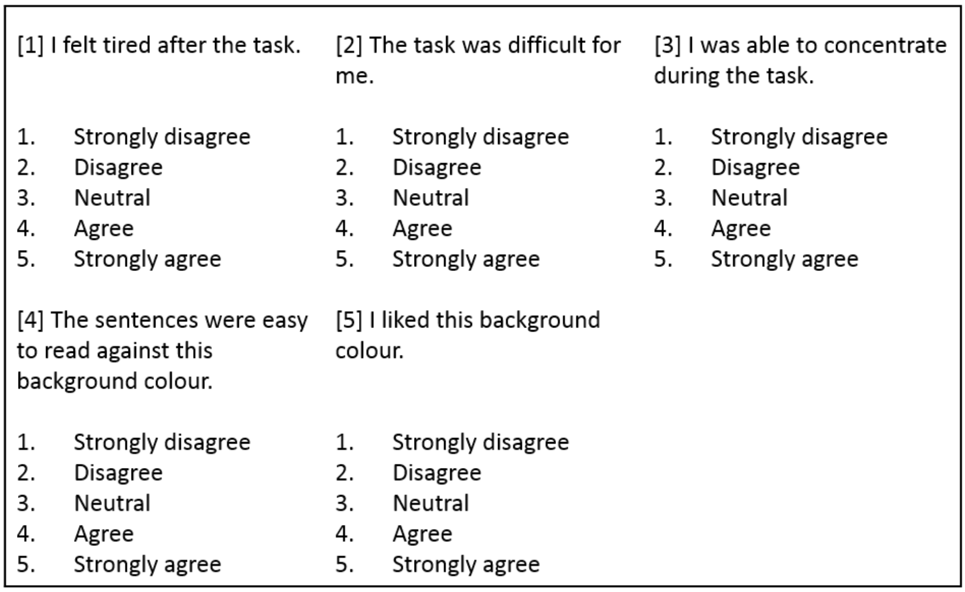
[4] この課題の画面は見やすかったですか。

1. 大変見にくかった
2. やや見にくかった
3. どちらともいえない
4. やや見やすかった
5. 非常に見やすかった

[5] この課題の画面の色は好きですか。

1. 非常に嫌い
2. やや嫌い
3. どちらともいえない
4. やや好き
5. 非常に好き

Figure 5.10: Questionnaire sample for brain training task with background colour



[1] I felt tired after the task.

1. Strongly disagree
2. Disagree
3. Neutral
4. Agree
5. Strongly agree

[2] The task was difficult for me.

1. Strongly disagree
2. Disagree
3. Neutral
4. Agree
5. Strongly agree

[3] I was able to concentrate during the task.

1. Strongly disagree
2. Disagree
3. Neutral
4. Agree
5. Strongly agree

[4] The sentences were easy to read against this background colour.

1. Strongly disagree
2. Disagree
3. Neutral
4. Agree
5. Strongly agree

[5] I liked this background colour.

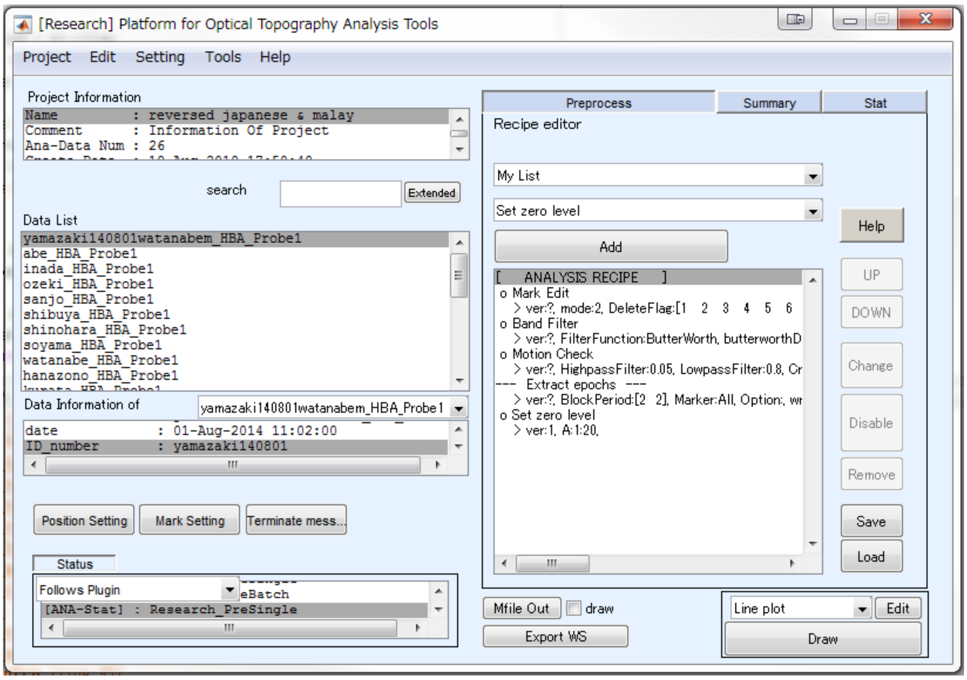
1. Strongly disagree
2. Disagree
3. Neutral
4. Agree
5. Strongly agree

Figure 5.11: English translation of questionnaire sample for brain training task with background colour

5.2.4 Data analysis

The oxy-Hb concentration changes in subjects' brains recorded during the experiment were averaged. The average NIRS signal value then will be compared and t-test statistical analysis will be performed on the average NIRS signal value to determine any significant differences. Furthermore, the recorded oxygenated haemoglobin (oxy-Hb) concentration changes will be plotted by using the Platform of Optical Topography Analysis Tools (POTATo).

POTATo is an integrated analytical environment for fNIRS signals, which is provided by NeU corporation. A POTATo is a MATLAB-based software which adapts the analysis framework of exploratory data analysis (EDA) proposed by John W. T., an American statistician in 1977. EDA focuses on the exploration of data characteristics, often with visual methods rather than the conventional hypothesis test and EDA offers more realistic data analysis. POTATo supports EDA by equipping various graphs for data visualization [53].



```
Name          : reversed japanese & malay
Comment       : Information Of Project
Ana-Data Num  : 26
```

```
yamazaki140801watanabem_HBA_Probe1
abe_HBA_Probe1
inada_HBA_Probe1
ozeki_HBA_Probe1
sanjo_HBA_Probe1
shibuya_HBA_Probe1
shinohara_HBA_Probe1
soyama_HBA_Probe1
watanabe_HBA_Probe1
hanazono_HBA_Probe1
```

Data Information of: yamazaki140801watanabem_HBA_Probe1

```
date            : 01-Aug-2014 11:02:00
ID_number       : yamazaki140801
```

Follows Plugin

```
[ANA-Stat] : Research_PreSingle
```

My List

Set zero level

```
[    ANALYSIS RECIPE    ]
 o Mark Edit
   > ver:?, mode:2, DeleteFlag:[1   2   3   4   5   6
 o Band Filter
   > ver:?, FilterFunction:ButterWorth, butterworthD
 o Motion Check
   > ver:?, HighpassFilter:0.05, LowpassFilter:0.8, Cr
---  Extract epochs  ---
   > ver:?, BlockPeriod:[2  2], Marker:All, Option:, wr
 o Set zero level
   > ver:1, A:1:20,
```

Line plot

FIGURE 5.12: POTATo (MATLAB based software)

Figure 5.12 shows the interface of the POTATo software. The NIRS signal usually contains a lot of biological noises because of the human brain, which is very complex and reacts easily even with a small stimulus. To obtain a better signal, it is necessary to remove the noises. Therefore, by using POTATo software, baseline processing was applied to clarify the change of reaction between before and after a task.

As shown in Figure 5.13, the average value of oxy-Hb concentration changes 'before' was defined as a baseline. Then the average value was subtracted from the value of oxy-Hb concentration changes 'task'. This procedure was applied for all phases and all of the channels to normalize NIRS signals and remove biological fluctuations. Besides, this process was also used as a basis for the averaging processing as shown in Figure 5.14. By averaging a few numbers of the same tasks, the data can be more clarified. In this study, the values of oxy-Hb concentration changes were added based on the task frequency on each background colour to calculate their value.

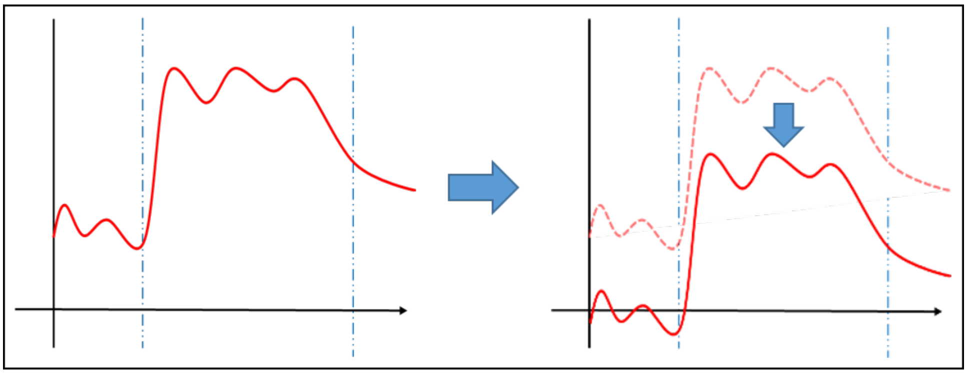


FIGURE 5.13: Baseline processing

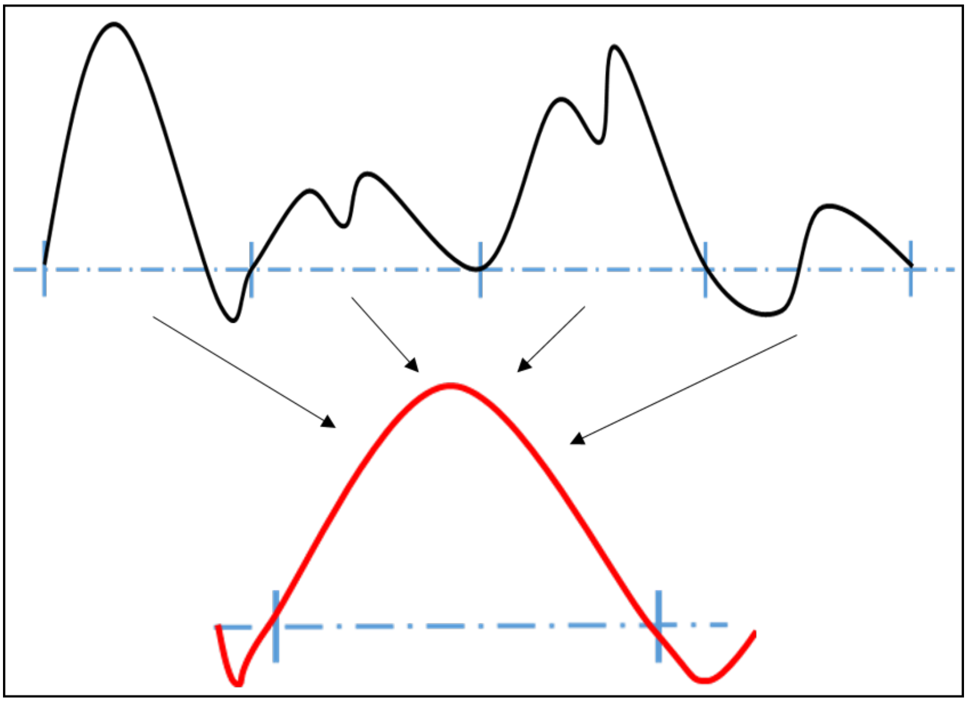


Figure 5.14: Averaging processing

5.3 CCT on five background colours

5.3.1 Cognitive task design

CCT was chosen to investigate the concentration areas of the brain as a focusing task. Five sets of the CCT represents five background colours which are white, blue, red, yellow, and green background colours with black text were developed for this experiment. Each test set consisted of ten CCT questions. All task pages were designed in the same way: three different symbols including circle were drawn randomly and presented in black on a single-color background of the tablet screen as shown from Figure 5.15 until Figure 5.19.

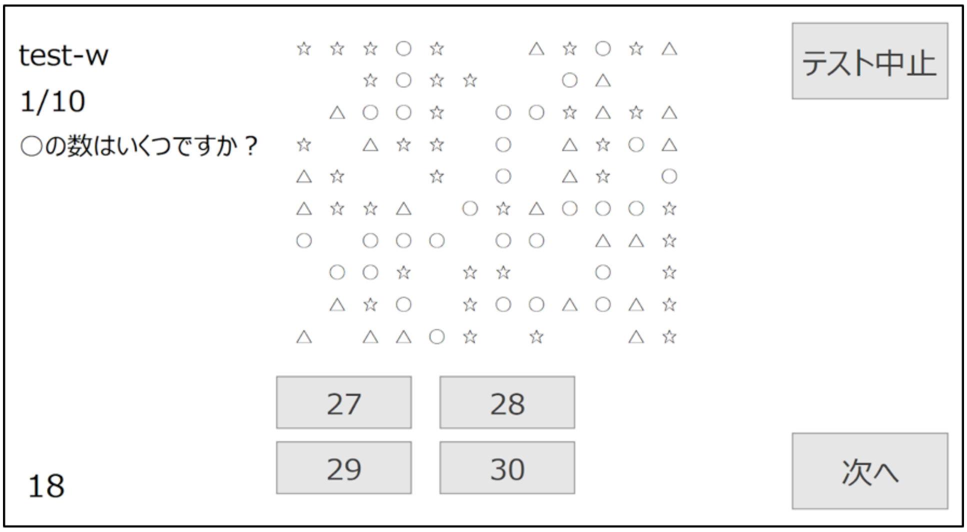
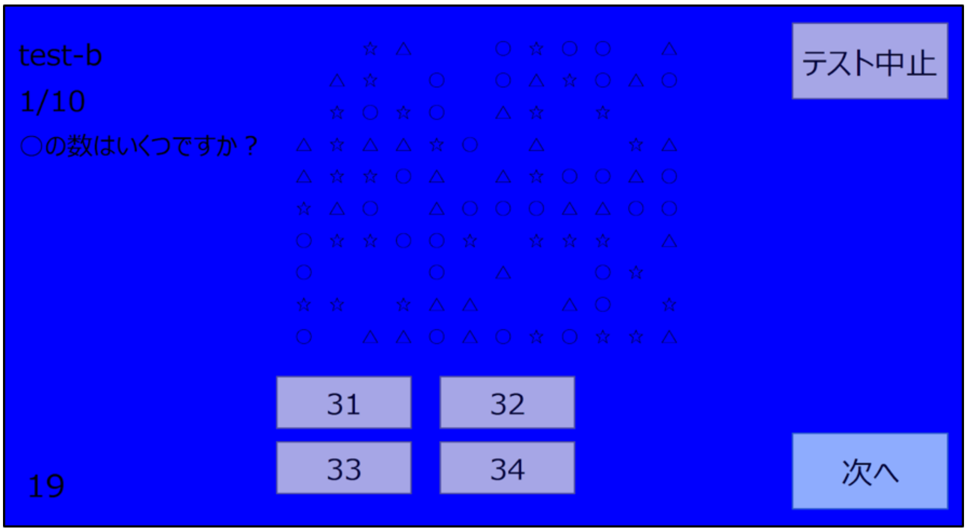
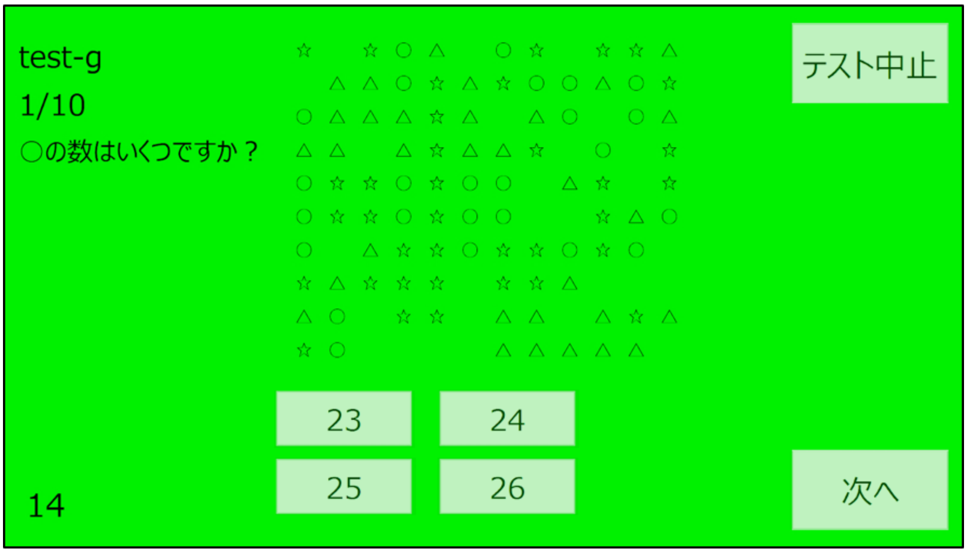


Figure 5.15: CCT on white background colour



○の数はいくつですか？

FIGURE 5.16: CCT on blue background colour



○の数はいくつですか？

FIGURE 5.17: CCT on green background colour

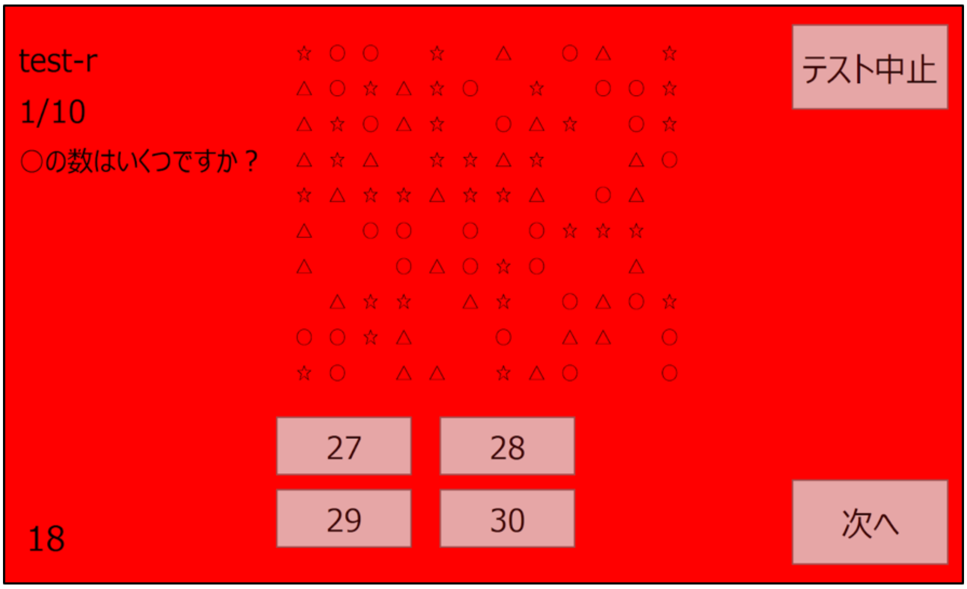


FIGURE 5.18: CCT on red background colour

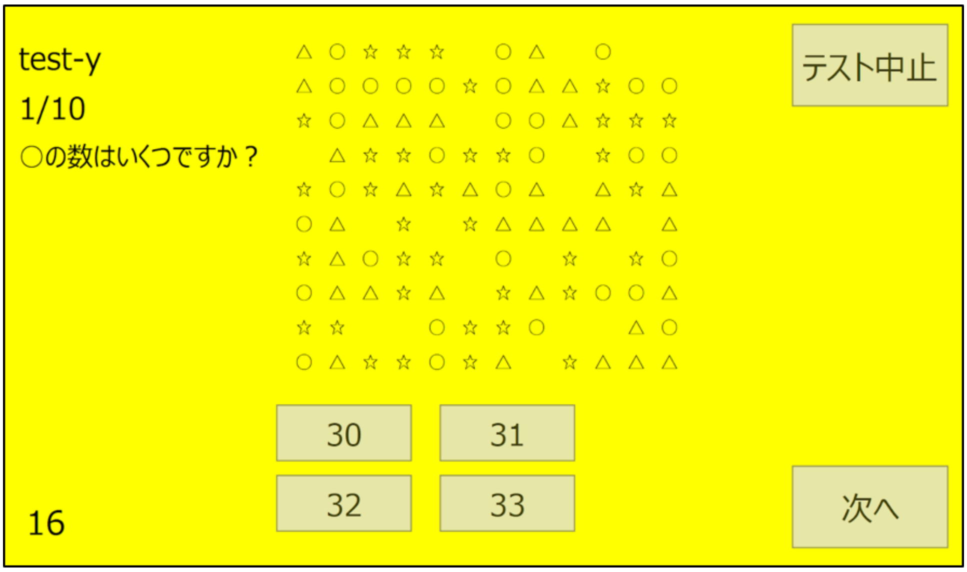


FIGURE 5.19: CCT on yellow background colour

5.3.2 Brain activity observation

Experimentation mostly had been discussed in section 5.2. A total of 30 Japanese subjects (20 young people, 10 elderly people) participated in the CCT experiment. 20 young people (15 males, 5 females) were university students (between 18-22 years old) and 10 elderly people (7 males, 3 females) (between 66-78 years old). The subjects were told to count the number of the circle on each background colour in a short period. The background colour sets were in random order for every subject. Figure 5.20 shows the block process of the CCT experiment. After completing the task for each background colour, the subjects responded to a designated questionnaire as discussed in 5.2.3. The NIRS value was recorded from the start until the end of the experiment.

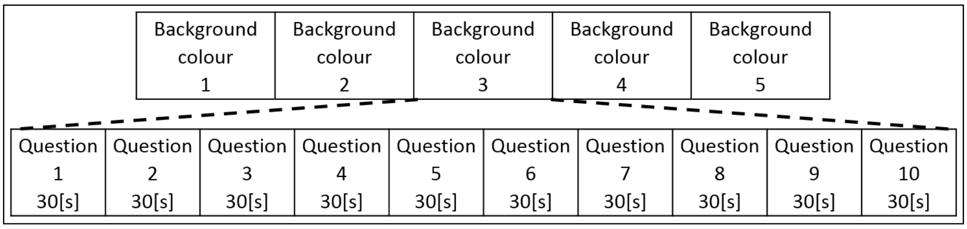


Figure 5.20: The block process of the CCT experiment

5.3.3 Results

CCT has 10 questions for each background colour and 10 as the highest score point for each has been calculated. The average percentages of the CCT score for each background colour were summarized in Figure 5.21. Figure 5.21 shows the average percentages of the CCT score for both young and elderly subjects. From Figure 5.21, the results show that the average percentages of the CCT score were the highest for the yellow background colour for both young and elderly subjects. However, the white background colour had the lowest average percentages of the CCT score for both young and elderly subjects.

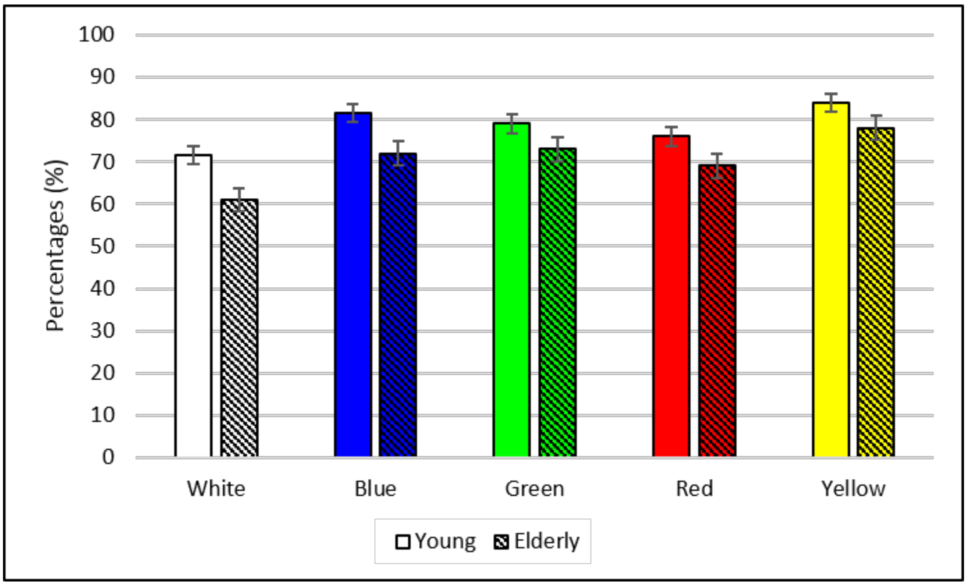


FIGURE 5.21: The average percentages of the CCT score

To find a significant difference between the average percentages of the CCT score for both young and elderly subjects, the t-test statistical analysis (α= 0.05) has been conducted. Table 5.2 summarizes the t-test statistical analysis results. From Table 5.2, the average percentages of the CCT score for the young subject is higher than the elderly subject. Furthermore, t-test statistical analysis stated that there is a significant difference (p<0.001) between the average percentages of the CCT score of young and elderly subjects.

TABLE 5.2: The average percentages of the CCT score t-test statistical analysis for young and elderly subjects (α= 0.05)

CCT score	Mean	Variance	t	p
Young	78.4***	23.675	8.3866	0.0006
Elderly	70.6	39.3		

***p<0.001

The authors then analysed variance (ANOVA) test (α= 0.05) to examine the significance of differences in the average percentages of CCT score among five background colours for both young and elderly subjects. Table 5.3 and Table 5.4 summarizes ANOVA test results for both young and elderly subjects respectively. Based on the results summarized in Table 5.3, the ANOVA test results demonstrated that there was a significant difference among the five background colours in the average percentages of the CCT score for the young subject. However, from Table 5.4, the ANOVA test results demonstrated that there was no significant difference among the five background colours in the average percentages of the CCT score for the elderly subject.

Table 5.3: The average percentages of the CCT score ANOVA test among five background colours for young subject (α= 0.05)

Background colour	Mean	Variance	*F*	*p*
White	71.5	297.6316	4.2109	0.0039**
Blue	81.5	202.8947		
Green	79	283.1579		
Red	76	362.1053		
Yellow	84	193.6842		

*p<0.05, **p<0.01

Table 5.4: The average percentages of the CCT score ANOVA test among five background colours for elderly subject ($\alpha = 0.05$)

Background colour	Mean	Variance	F	p
White	61	654.4444	2.2148	0.0868
Blue	72	817.7778		
Green	73	534.4444		
Red	69	321.1111		
Yellow	78	395.5556		

The author also then conducted a t-test statistical analysis ($\alpha = 0.05$) on the average percentages of the CCT scores for both young and elderly subjects of every background colour with white background colour since white background colour is the commonly used as a screen background colour. Table 5.5 and Table 5.6 shows the summary of t-test statistical analysis conducted on the average percentages of CCT score for both young and elderly subjects to determine a significant difference between each background colour with the white background colour.

Table 5.5: The average percentages of the CCT score t-test statistical analysis between each background colour with white background colour for young subject (α= 0.05)

Background colour	Mean	Variance	t	p
White	71.5	297.6316	-2.7568	0.0063
Blue	81.5**	202.8947		
White	71.5	297.6316	-2.2627	0.0178
Green	79*	283.1579		
White	71.5	297.6316	-1.5768	0.0657
Red	76	362.1053		
White	71.5	297.6316	-3.1523	0.0026
Yellow	84**	193.6842		

*p<0.05, **p<0.01

Table 5.6: The average percentages of the CCT score t-test statistical analysis between each background colour with white background colour for elderly subject ($\alpha = 0.05$)

Background colour	Mean	Variance	*t*	*p*
White	61	654.4444	-2.012	0.0375
Blue	72*	817.7778		
White	61	654.4444	-1.7241	0.0594
Green	73	534.4444		
White	61	654.4444	-1.7143	0.0603
Red	69	321.1111		
White	61	654.4444	-2.2344	0.0262
Yellow	78*	395.5556		

*$p < 0.05$

The results from Table 5.5 demonstrates that the average percentages of the CCT score on blue, green, and yellow background colours have significant differences ($p<0.05$) and ($p<0.01$) between the average percentages of the CCT score on a white background colour for the young subject. On the other hand, Table 5.6 reveals that the average percentages of the CCT score on yellow and blue background colours have significant differences ($p<0.05$) between the average percentages of the CCT score on a white background colour for the elderly subject. For all 30 subjects, the oxy-Hb concentration changes also which has been recorded by using wearable NIRS system during the experiment will be analysed. For each subject, the values of oxy-Hb concentration changes measured every 0.2[s] were averaged for each background colour for both young and elderly subjects. These values are referred to as average

NIRS signal values. Figure 5.22 shows the average NIRS value for each background colour of young and elderly subjects.

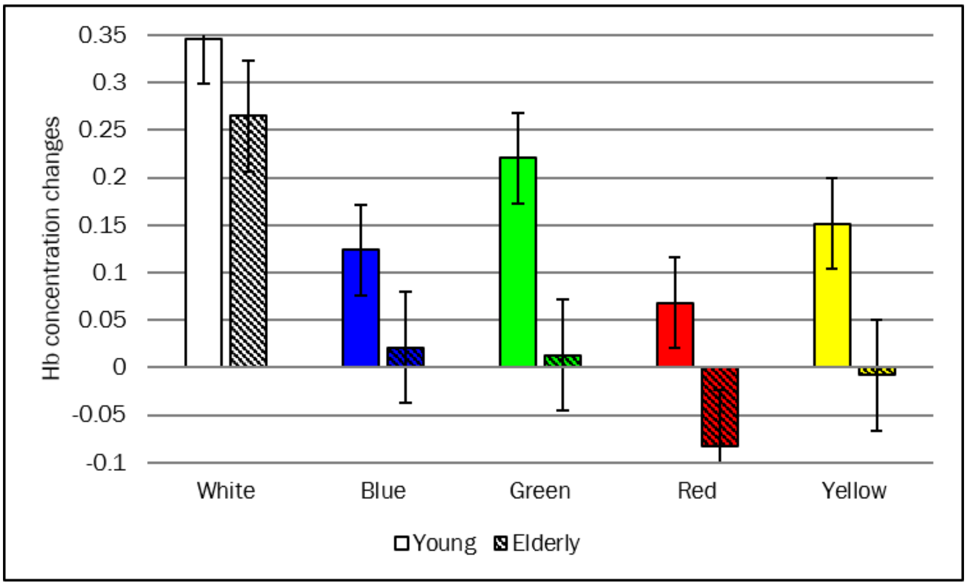


FIGURE 5.22: The average NIRS value of the CCT

Figure 5.22 shows that white background colour activated the frontal area of the brain the most for both young and elderly subjects for CCT. Next, to compare which one that activated the brain functions, we analysed the average NIRS signal values by using t-test statistical analysis (α= 0.05). The overall t-test statistical analysis result between young and elderly subjects was shown in Table 5.7.

TABLE 5.7: The average NIRS signal value t-test statistical analysis for young and elderly subjects (α= 0.05)

NIRS signal value	Mean	Variance	t	p
Young	0.1821**	0.0114	6.3127	0.0016
Elderly	0.0416	0.0172		

**p<0.01

Based on Table 5.7, the young subject had higher average NIRS value compared to the elderly subject when performed CCT. Furthermore, t-test statistical analysis reveals a significant difference ($p<0.01$) between the average NIRS value of young and elderly subjects. Then, we further analysed the data for each background colour since we used five different background colours (white, blue, green, red, yellow) in this experiment. Table 5.8 and Table 5.9 shows each background colour ANOVA test ($\alpha = 0.05$) for both young and elderly subjects.

TABLE 5.8: The average NIRS value ANOVA test among five background colours for young subject ($\alpha = 0.05$)

Background colour	Mean	Variance	F	p
White	0.3462	0.0461	2.6921	0.0393*
Blue	0.124	0.0667		
Green	0.2208	0.1229		
Red	0.0679	0.0613		
Yellow	0.1517	0.0303		

*$p<0.05$

TABLE 5.9: The average NIRS value ANOVA test among five background colours for elderly subject ($\alpha = 0.05$)

Background colour	Mean	Variance	F	p
White	0.2647	0.0606	2.7277	0.0374*
Blue	0.0211	0.062		
Green	0.0129	0.1443		
Red	-0.0829	0.3891		
Yellow	-0.008	0.2147		

*$p<0.05$

Table 5.8 and 5.9 stated the same tendency which white background colour has the highest NIRS signal value, while the red background colour has the lowest NIRS signal value. The ANOVA test also expressed significant differences ($p<0.05$) for the NIRS signal values. Then, we analysed the NIRS signal values in further details by examining the NIRS topography recorded during the experiment. The topography of oxy-Hb images data from all subjects were averaged. Figure 5.23 and Figure 5.24 show the oxy-Hb topography images of each background colour for both young and elderly subjects respectively.

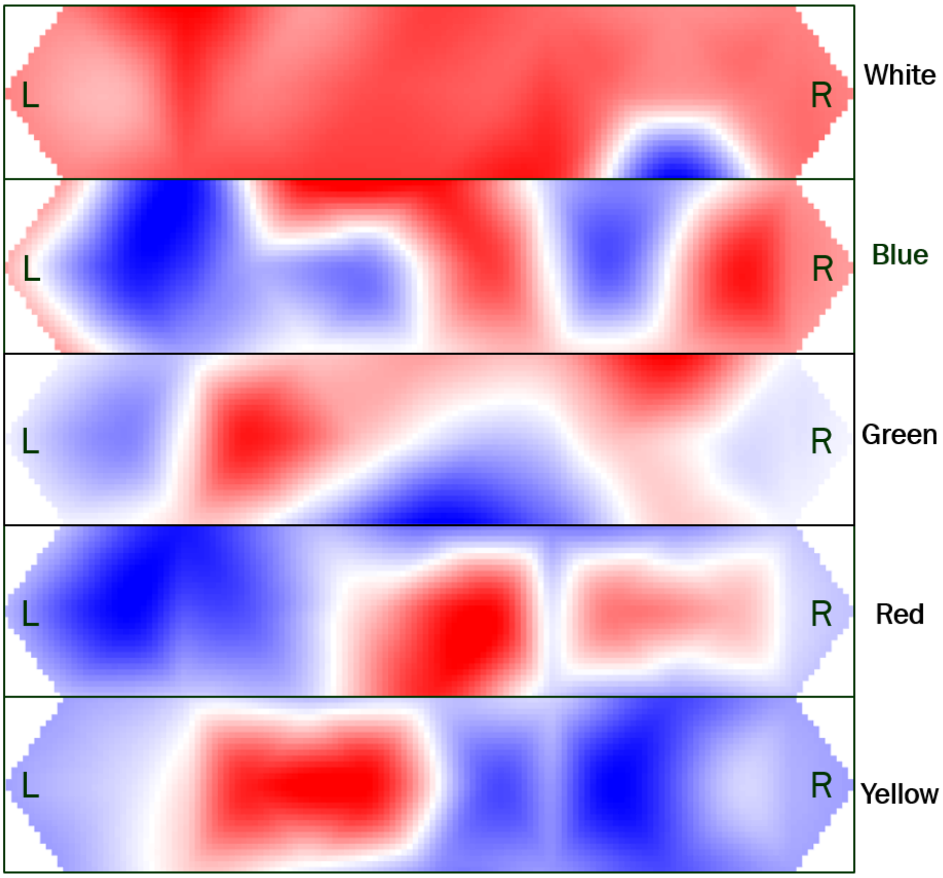


FIGURE 5.23: Average oxy-Hb topography images of CCT for young subjects on each background colour

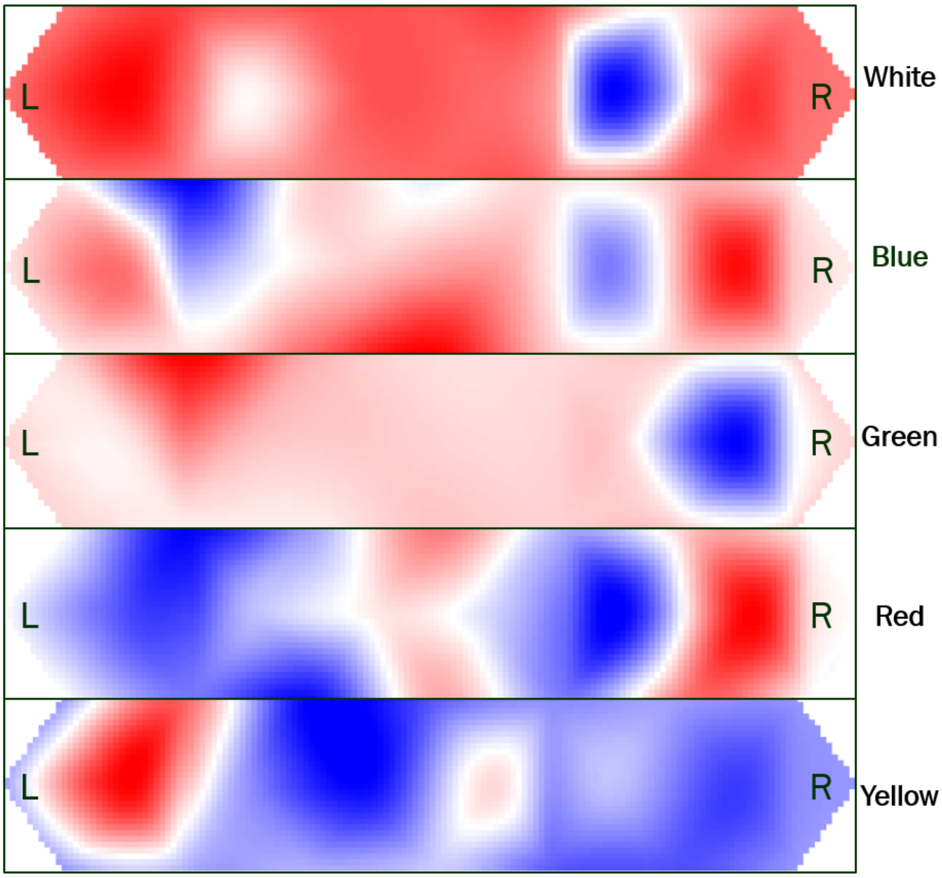


FIGURE 5.24: Average oxy-Hb topography images of CCT for elderly subjects on each background colour

Figure 5.23 and Figure 5.24 show the average oxy-Hb topography images of both young and elderly subjects respectively. Red region represents high activation while blue region represents low activation of the area. From both figures, we observed the same tendency which is higher activation when both young and elderly subjects performed CCT on the white background colour. We then analysed the questionnaire answered by subjects right after they finish performed the CCT. Figures 5.25 summarize the average value of responses to the questionnaire items answered by both young and elderly subjects for each background colour. The questionnaire asked the subjects to rate only their tiredness, readability, difficulty, and concentration levels on a five-point Likert scale.

Overall, it may be said that both young and elderly subjects performed the lowest on the white background colour. However, the subjects' brain displayed a higher rate of changes in oxy-Hb on white background colour in comparison to other background colours. From questionnaire results, we can understand that young subject felt least tired and can concentrate the most on white background colour even though the average percentages of CCT score is the lowest. However, the elderly subject stated that they felt most tired on white background colour which affected higher average NIRS value.

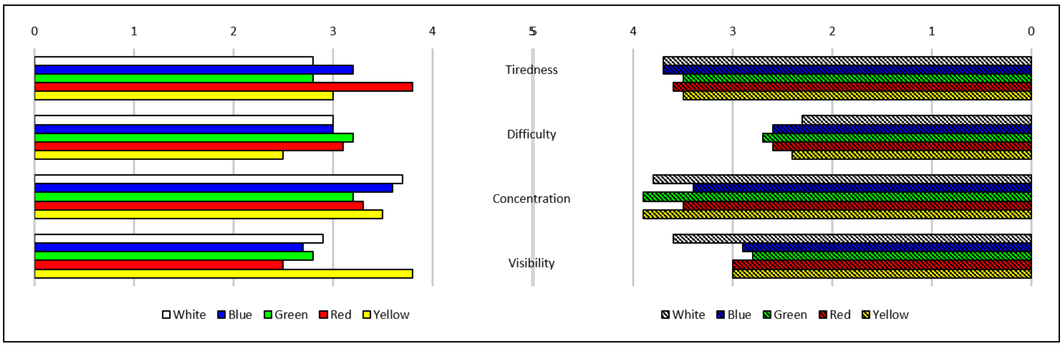
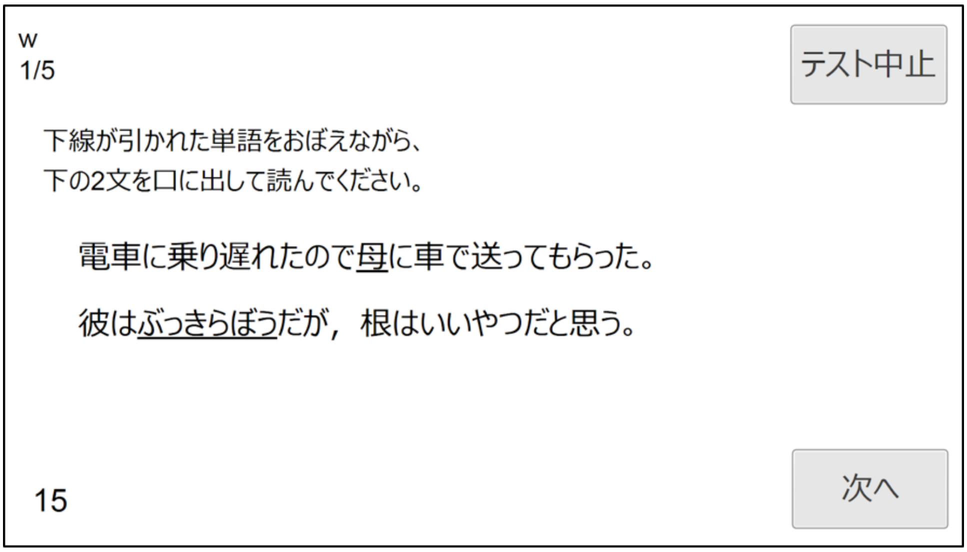


Figure 5.25: Questionnaire answered by young subject (left) and elderly subject (right)

5.4 RST on five background colours

5.4.1 Cognitive task design

RST is a common task used to test working memory and reading comprehension. Five sets of RST represent five background colours which are white, blue, red, yellow, and green background colours with black text were developed for this experiment. Each test set consisted of five RST questions. A total of 67 sentences were obtained from the original Japanese RST [70][71][72]. All task pages were designed in the same way: two sentences with one underlined word each in a short Japanese sentence were presented in black on a single-colour background of a tablet screen as shown in Figure 5.26 until Figure 5.30.

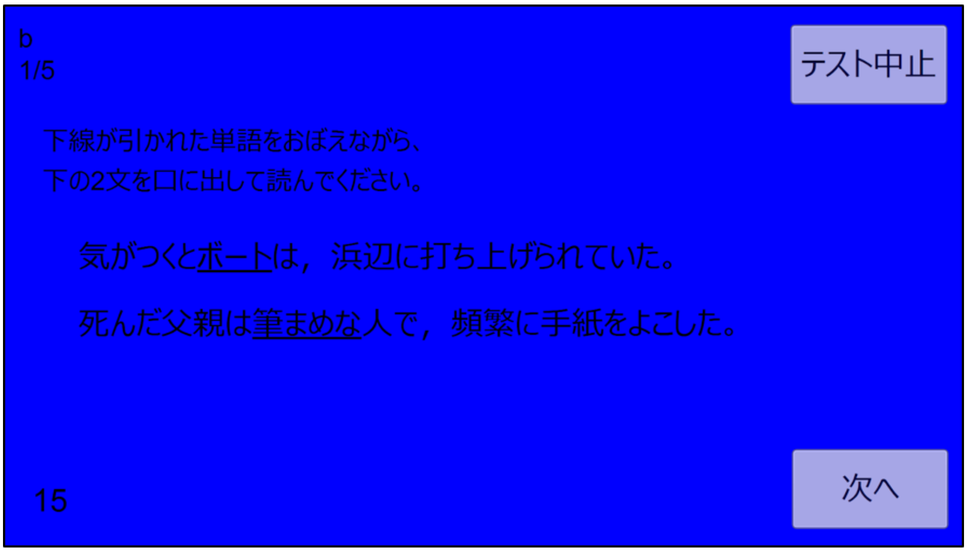


下線が引かれた単語をおぼえながら、
下の2文を口に出して読んでください。

電車に乗り遅れたので母に車で送ってもらった。

彼はぶっきらぼうだが，根はいいやつだと思う。

FIGURE 5.26: RST on white background colour

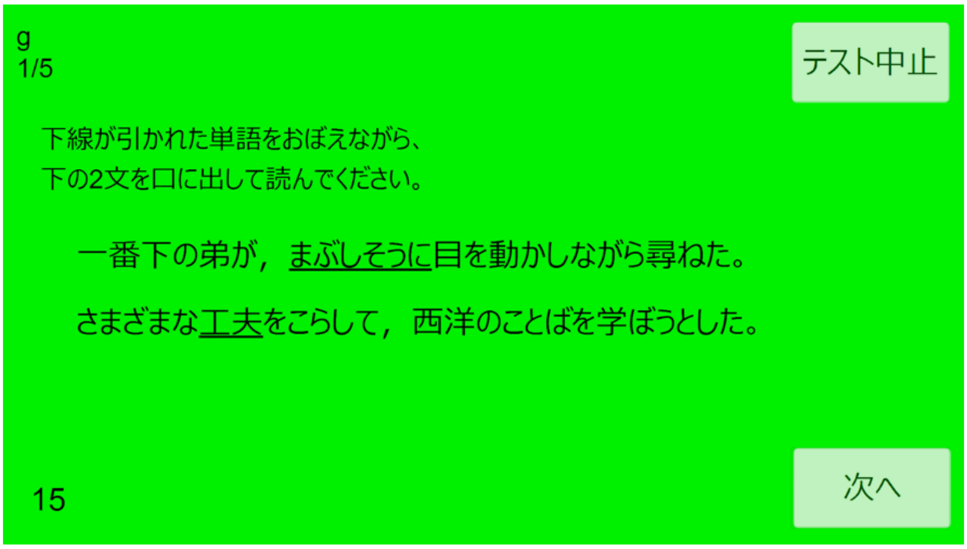


下線が引かれた単語をおぼえながら、
下の2文を口に出して読んでください。

気がつくとボートは，浜辺に打ち上げられていた。

死んだ父親は筆まめな人で，頻繁に手紙をよこした。

FIGURE 5.27: RST on blue background colour

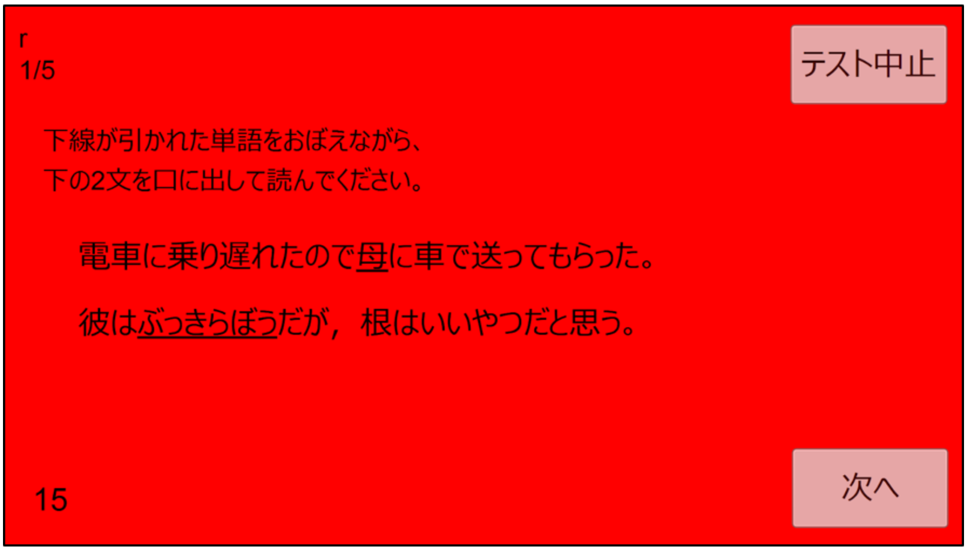


下線が引かれた単語をおぼえながら、
下の2文を口に出して読んでください。

一番下の弟が，まぶしそうに目を動かしながら尋ねた。

さまざまな工夫をこらして，西洋のことばを学ぼうとした。

FIGURE 5.28: RST on green background colour

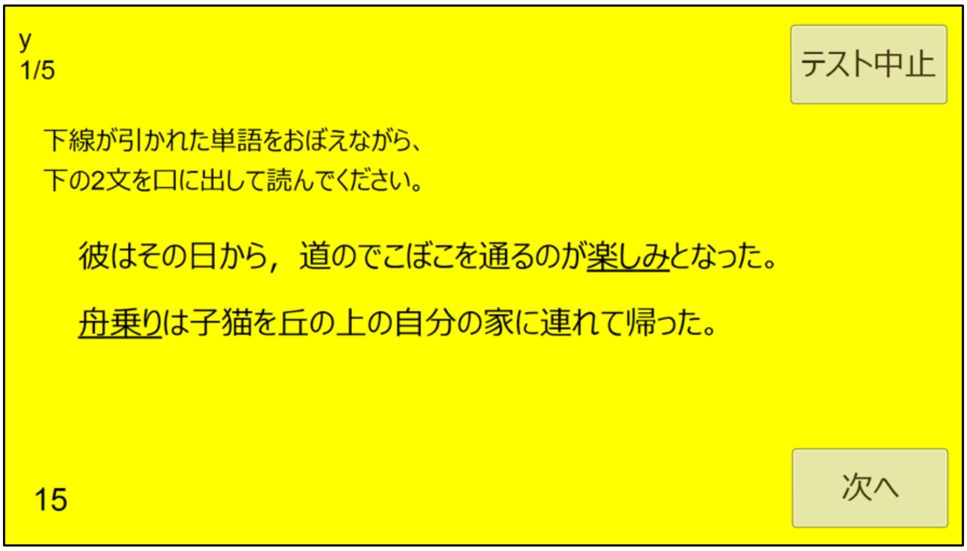


下線が引かれた単語をおぼえながら、
下の2文を口に出して読んでください。

電車に乗り遅れたので母に車で送ってもらった。

彼はぶっきらぼうだが，根はいいやつだと思う。

FIGURE 5.29: RST on red background colour



下線が引かれた単語をおぼえながら、
下の2文を口に出して読んでください。

彼はその日から，道のでこぼこを通るのが楽しみとなった。

舟乗りは子猫を丘の上の自分の家に連れて帰った。

FIGURE 5.30: RST on yellow background colour

5.4.2 Brain activity observation

Experimentation mostly had been discussed in section 5.2. A total of 29 Japanese subjects (22 young people, 7 elderly people) participated in the RST experiment. 22 young people (18 males, 4 females) were university students (between 18-25 years old) and 7 elderly people (4 males, 3 females) (between 69-79 years old).

The subjects were told to memorize the underlined words in the sentences while reading the sentences aloud on each background colour. Then, the subjects need to recall the underlined words and say them aloud in a short period. The rule was, the target word of the last sentences should not be recalled as a first word. A blank page with respective background colour appeared at every interval of the questions for 10 seconds. This page was used as a resting task for subjects' brain. Figure 5.31 shows the block process of the RST experiment. After completing the task for each background colour, the subjects responded to a designated questionnaire as discussed in 5.2.3. The NIRS value was recorded from the start until the end of the experiment.

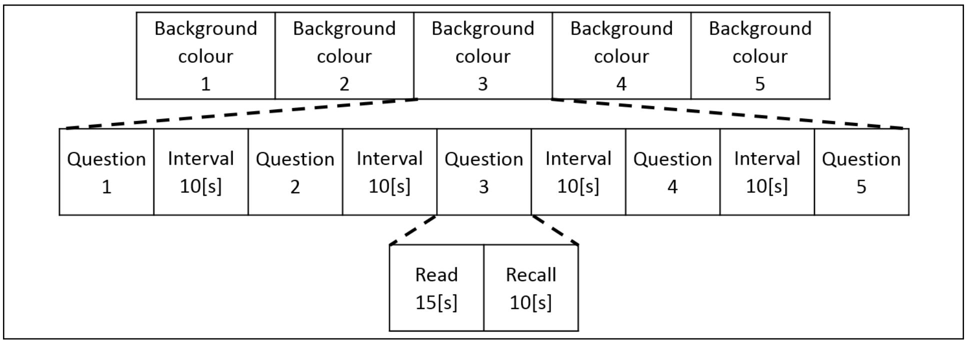


FIGURE 5.31: The block process of the RST experiment

5.4.3 Results

The total number of sentences in each background colour is 10 sentences and make a total of 10 target words. There are four scoring methods for the RST. The first method is total words recall method. A total of 10 sentences consist of 10 target words that will make 10 as a high score point. The next method is the proportion of words recall method. For example, if the subject can only recall one word out of two words, subject only receives 0.5 points. The score then will be averaged with all and makes 1.0 as highest score point for proportion words recall method.

Then, we have the correct set words method. For example, if the subject recalls two words, the subject will receive 2 points. If subject only recall one word out of two words, the score would be 0 and this method makes 10 points as a high score. The last method is the truncated span. Truncated span method can be used for the level type of RST. For example, if the subject recalled three out of six at a certain level, half a point will be given. The maximum possible score for each level is 1 point. However, to advance to the next level, the subject had to have passed the previous level.

In this study, the author decided to choose the first method, which is the total words recall, in this study. It is said that the variance is large and the correlation with reliability and reading comprehension is also high for the total words recall and the proportion words recall methods. Normality verification by Friedman and

Miyake stated that in the test of kurtosis, skewness, and normality, the normality was guaranteed for the total words recall and the proportion words recall methods, but the normality was not guaranteed for the correct set words method and the truncated span [73].

The average percentages of the RST score for each background colour were calculated and summarized in Figure 5.32. Figure 5.32 shows the average percentages of the RST score for both young and elderly subjects. From Figure 5.32, the results show that the average percentages of the RST score were the highest on the yellow background colour and the lowest on a red background colour for the young subject. However, the yellow background colour had the lowest and white background colour had the highest average percentages of the RST score for the elderly subject.

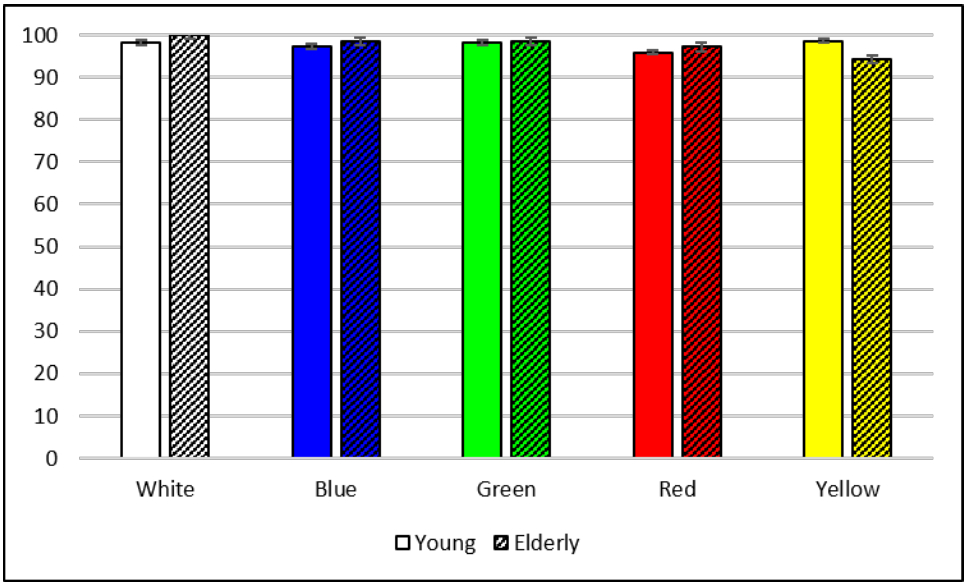


FIGURE 5.32: The process of the RST experiment

To find a significant difference between the average percentages of the RST score for both young and elderly subjects, the t-test statistical analysis (α= 0.05) has been conducted. Table 5.10 summarizes the t-test statistical analysis results. From Table 5.10, the average percentages of the RST score for the young subject is lower than the elderly subject. However, t-test statistical analysis stated that there is no significant difference between the average percentages of the RST score of young and elderly subjects.

TABLE 5.10: The average percentages of the RST score t-test statistical analysis for young and elderly subjects (α= 0.05)

RST score	Mean	Variance	t	p
Young	97.6363	1.1777	-0.0689	0.4742
Elderly	97.7143	4.6939		

The authors also analysed variance (ANOVA) test (α= 0.05) to examine the significance of differences in the average percentages of RST score among five background colours for both young and elderly subjects. Table 5.11 and Table 5.12 summarizes ANOVA test results for both young and elderly subjects respectively. Based on the results summarized in Table 5.11 and Table 5.12, the ANOVA test results demonstrated that there was no significant difference among five background colours in the average percentages of the RST score for both young and elderly subjects.

TABLE 5.11: The average percentages of the RST score ANOVA test among five background colours for young subject (α= 0.05)

Background colour	Mean	Variance	F	p
White	98.1818	44.1558	0.7412	0.5666
Blue	97.2727	20.7792		
Green	98.1818	25.1082		
Red	95.9091	63.4199		
Yellow	98.6364	40.9091		

Table 5.12: The average percentages of the RST score ANOVA test among five background colours for elderly subject (α= 0.05)

Background colour	Mean	Variance	F	p
White	100	0	0.8313	0.5185
Blue	98.5714	14.2857		
Green	98.5714	14.2857		
Red	97.1429	23.8095		
Yellow	94.2857	128.5714		

For all 29 subjects, the oxy-Hb concentration changes also which has been recorded by using wearable NIRS system during the experiment will be analysed. For each subject, the values of oxy-Hb concentration changes measured every 0.2[s] were averaged for each background colour for both young and elderly subjects. These values are referred to as average NIRS signal values. Figure 5.33 shows the average NIRS value for each background colour of young and elderly subjects.

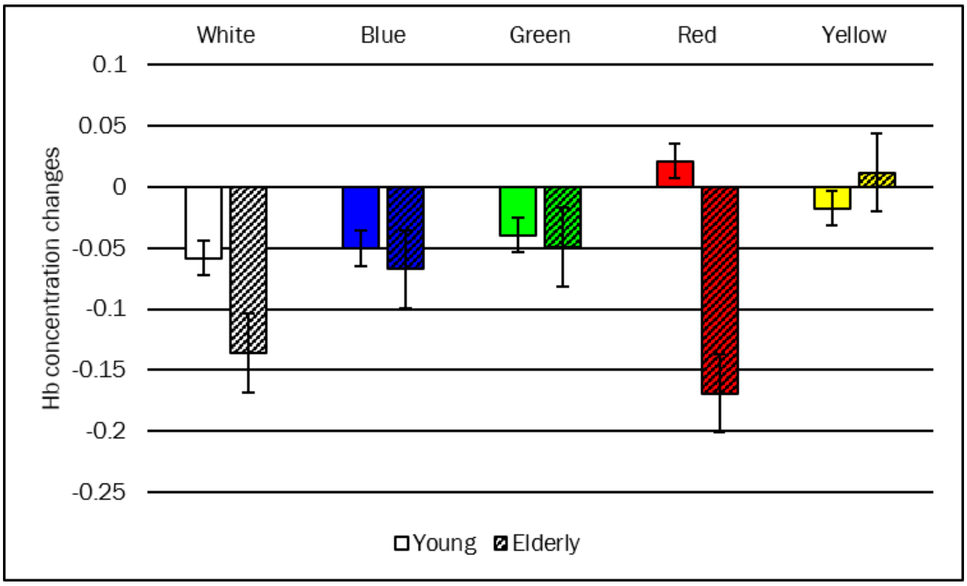


FIGURE 5.33: The average NIRS value of the RST on five background colours

Figure 5.33 shows that most of the background colours did not activated the frontal area of the brain for both subject groups. Only red background colour activated young subjects' frontal area, while only yellow background colour activated elderly subjects' frontal area of the brain. To analyse the recorded data in details, we used t-test statistical analysis (α= 0.05). The overall t-test statistical analysis result between young and elderly subjects was shown in Table 5.13.

TABLE 5.13: The average NIRS signal value t-test statistical analysis for young and elderly subjects (α= 0.05)

NIRS signal value	Mean	Variance	t	p
Young	-0.0288	0.0091	1.0408	0.1572
Elderly	-0.0819	0.0409		

Based on Table 5.13, the young subject had higher average NIRS value compared to the elderly subject when performed RST. However, t-test statistical analysis reveals no significant difference between the average NIRS value of young and elderly subjects. Then, we further analysed the data for each background colour since we used five different background colours (white, blue, green, red, yellow) in this experiment. Table 5.14 and Table 5.15 shows each background colour ANOVA test (α= 0.05) for both young and elderly subjects.

TABLE 5.14: The average NIRS value ANOVA test among five background colours for young subject (α= 0.05)

Background colour	Mean	Variance	F	p
White	-0.0583	0.0299	0.4159	0.7965
Blue	-0.0501	0.1207		
Green	-0.0394	0.0197		
Red	0.0214	0.0142		
Yellow	-0.0176	0.0181		

Table 5.15: The average NIRS value ANOVA test among five background colours for elderly subject ($\alpha = 0.05$)

Background colour	Mean	Variance	F	p
White	-0.1359	0.1367	3.2111	0.0187*
Blue	-0.0672	0.0217		
Green	-0.0493	0.0677		
Red	-0.1691	0.0687		
Yellow	0.012	0.0122		

*p<0.05

Table 5.14 stated that red background colour has the highest NIRS signal value, while the white background colour has the lowest NIRS signal value for the young subject. However, the ANOVA test reveals no significant difference in the NIRS signal values. On the other hand, Table 5.15 stated that red background colour has the lowest NIRS signal value, while a yellow background colour has the highest NIRS signal value for the elderly subject. Furthermore, the ANOVA test reveals a significant difference (p<0.05) for the NIRS signal values. Then, we analysed the NIRS signal values in further details by examining the NIRS topography recorded during the experiment. The oxy-Hb topography images data from all subjects were averaged. Figure 5.34 and Figure 5.35 show the oxy-Hb topography images of each background colour for both young and elderly subjects respectively.

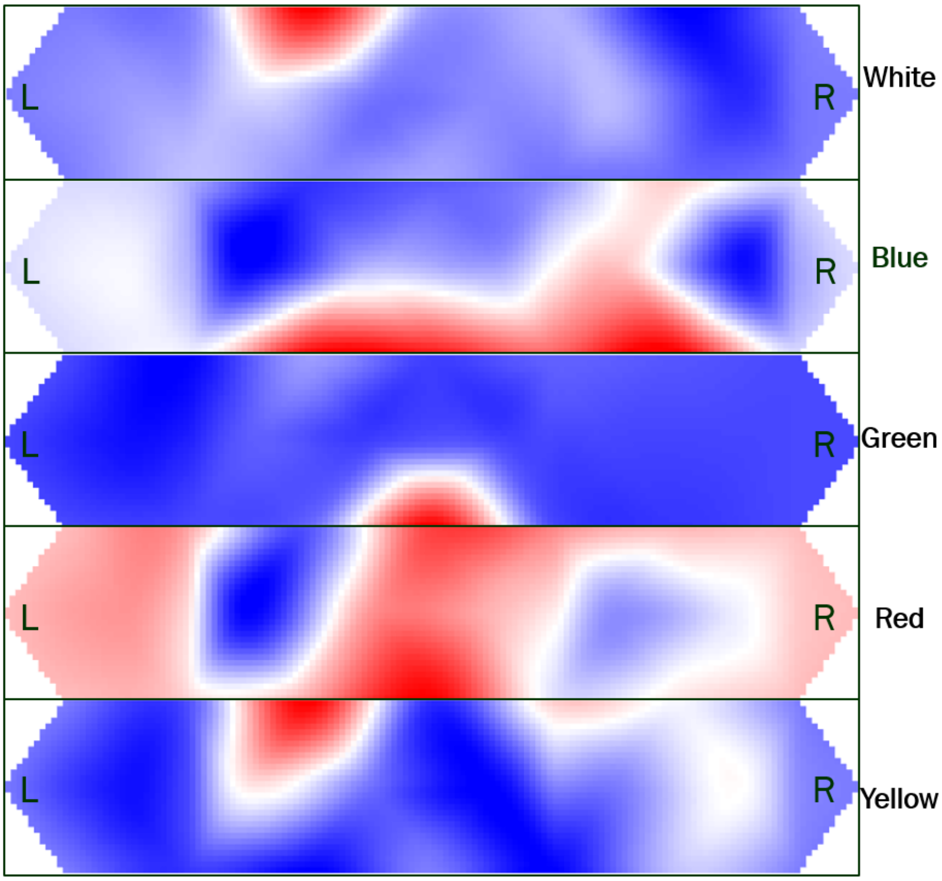


FIGURE 5.34: Average oxy-Hb topography images of RST for young subjects on each background colour

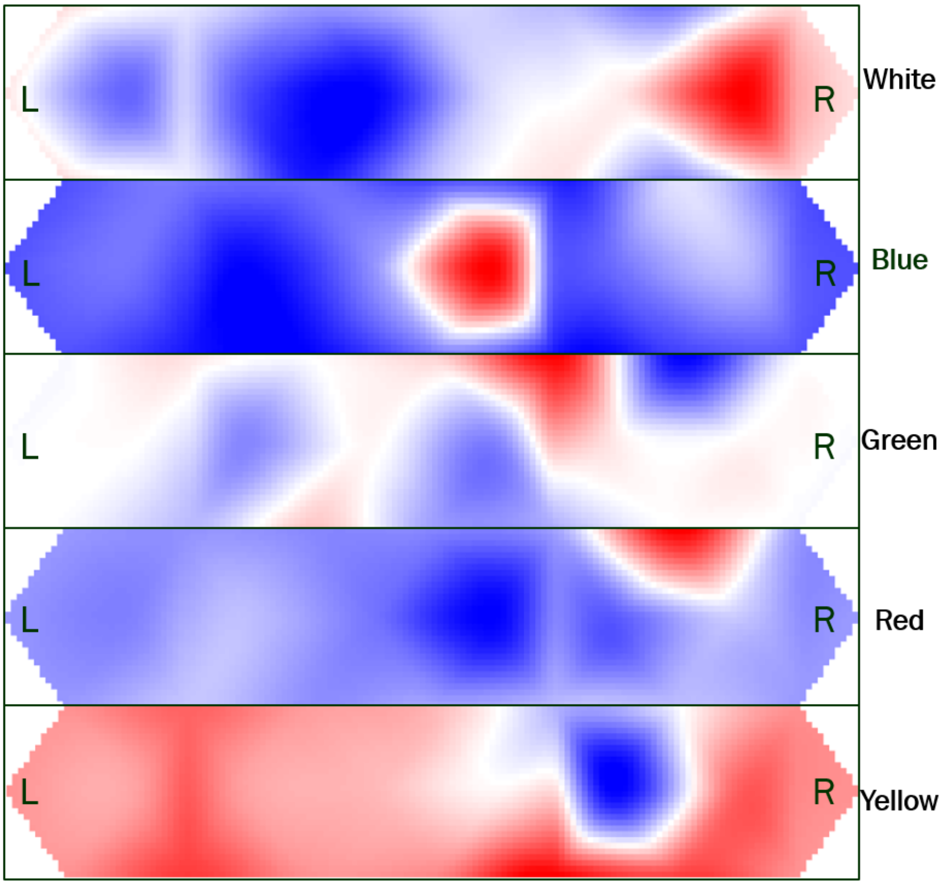


FIGURE 5.35: Average oxy-Hb topography images of RST for elderly subjects on each background colour

Figure 5.34 and Figure 5.35 show the average oxy-Hb topography images of both young and elderly subjects respectively. Red region represents high activation while blue region represents low activation of the area. From both figures, we observed that red background colour has higher activations on young subjects' frontal area of the brain for RST, while yellow background colour has higher activations on elderly subjects' frontal area of the brain for RST. We then analysed the questionnaire answered by subjects right after they finish performed the RST. Figures 5.36 summarize the average value of responses to the questionnaire items answered by both young and elderly subjects for each background colour. The questionnaire asked the subjects to rate their tiredness, readability, difficulty, colour preferences, and concentration levels on a five-point Likert scale.

Overall, it may be said that the young subject performed the lowest on the red background colour and elderly subject performed the lowest on the yellow background colour. However, the subjects' brain displayed a higher rate of changes in oxy-Hb on a red background colour for a young and yellow background colour for the elderly. From questionnaire results, we can understand that young subject felt most tired on a red background colour that causes the average percentages of RST score is the lowest and had higher oxy-Hb concentration changes. However, the elderly subject stated different reason where they could not concentrate the most on the yellow background colour.

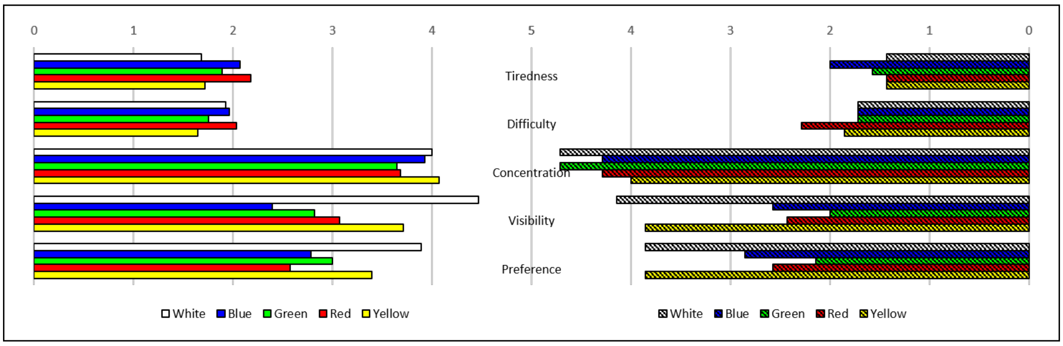


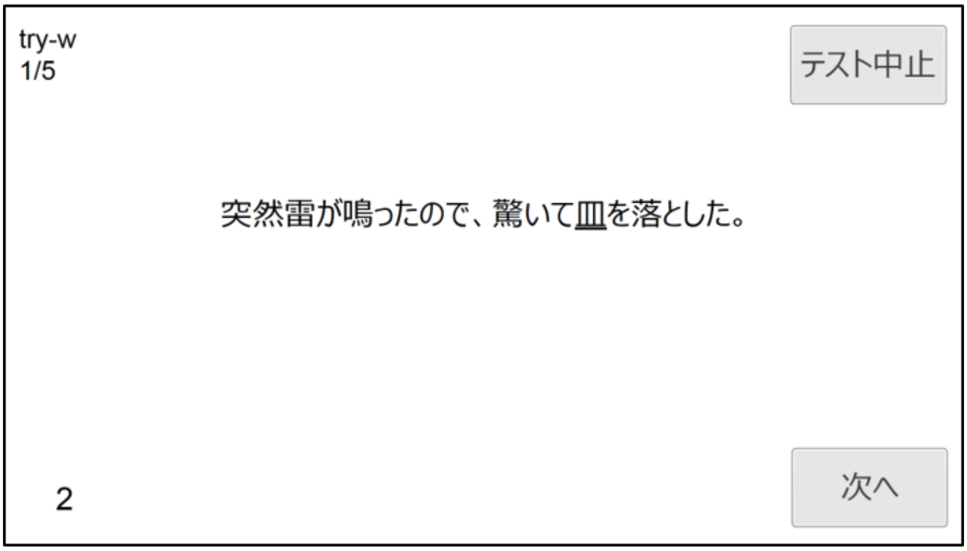
FIGURE 5.36: Questionnaire answered by young subject (left) and elderly subject (right)

5.5 RST on three background colours

5.5.1 Cognitive task design

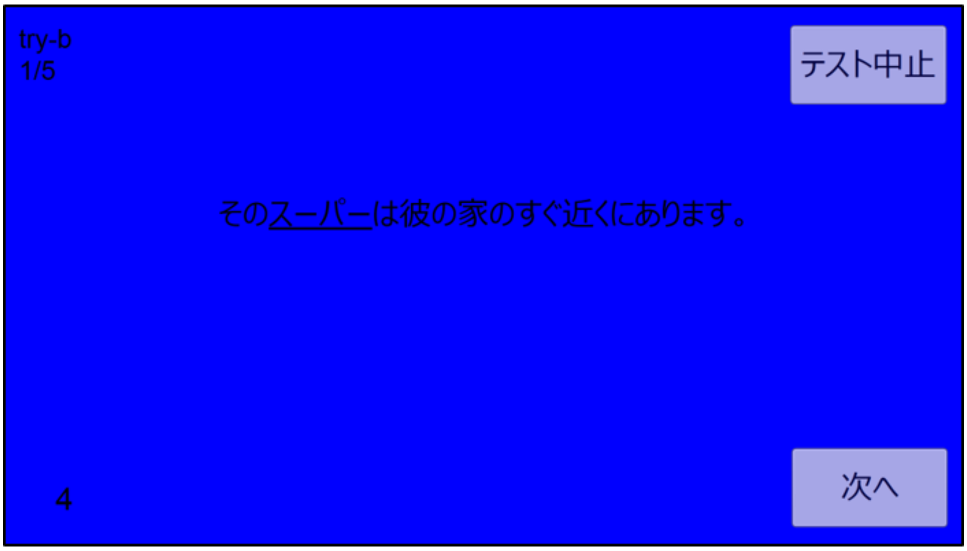
Previously, the authors used five different background colours to explore the effects of brain training tasks given to groups of young and elderly subjects. In this present study, the authors focused on the use of RST to test brain functions for the colours that were known as better background colours for readability which were white, blue, and green. Hence, three sets of RSTs for each background colour were developed. Each test set consisted of five levels of RST questions. Each level consisted of a different number of sentences, starting with two sentences for the first level and each consecutive level's being increased by one sentence to give a total of 20 sentences in one set.

All the question pages had the same design with each sentence displaying one underlined word in black font against a single-colour background. One sentence was displayed at a time. The subjects were asked to memorise the underlined word while reading each sentence aloud and recall the underlined words aloud within a short period. There was no rule for the order of the words recalled. Used as a resting task, a blank page with the respective background colour appeared at every interval for 10 seconds. All the questions and designs refer to the original standard computerised version of the RST [74][75]. The same sentences were obtained from section 5.4.1 [70][71][72]. Figure 5.37 until Figure 5.39 show an example of the question pages.



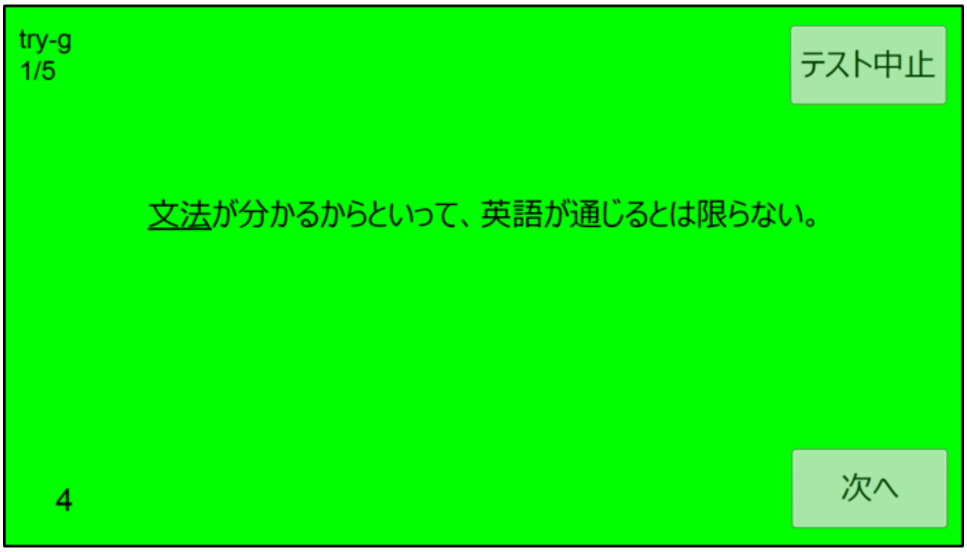
突然雷が鳴ったので、驚いて皿を落とした。

Figure 5.37: Reading span task on white background colour



そのスーパーは彼の家のすぐ近くにあります。

FIGURE 5.38: Reading span task on blue background colour



文法が分かるからといって、英語が通じるとは限らない。

FIGURE 5.39: Reading span task on green background colour

5.5.2 Brain activity observation

Thirty native Japanese university students (27 males, 3 females) (between 18-26 years old) and 17 elderly people (11 males, 6 females) (between 65-81 years old) participated in this study. They were asked to memorise 20 words in total for each background colour. The corresponding 20 sentences had been randomly chosen out of 67 sentences in the original Japanese RST and were divided into five levels, each of which consisted of a different number of sentences. The time given to the subjects to read each sentence and memorise the underlined word was fixed at 6.5[s].

After all the sentences in each level were read, they were asked to recall the underlined words in the time given for each level. Then, a blank page with the respective background colour appeared for 10[s] before the next level was attempted. Figure 5.40 shows the block process of the reading span task experiment. After completing the task for each background colour, the subjects responded to a designated questionnaire as discussed in 5.2.3. The NIRS value was recorded from the start until the end of the experiment.

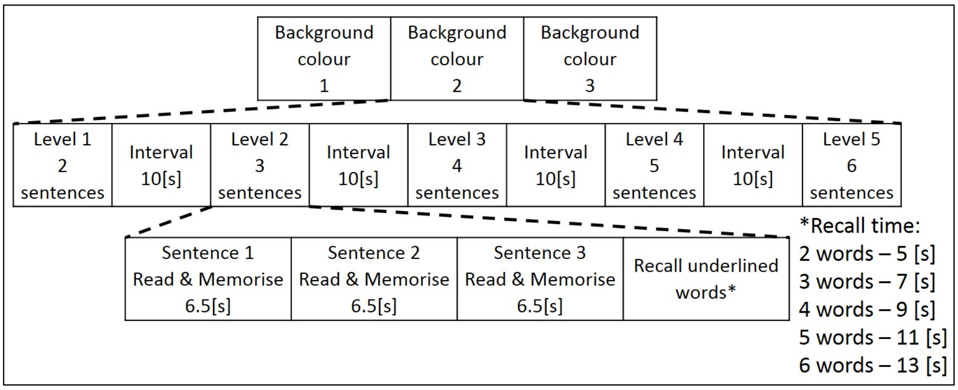


FIGURE 5.40: The process of the reading span task experiment

5.5.3 Results

The total number of sentences in each background colour are 20 sentences and make a total of 20 target words. As well as previous RST, the author decided to choose the first method, which is the total words recall, in this study. The average percentages of the RST score for each background colour were calculated and summarized in Figure 5.41. Figure 5.41 shows the average percentages of the RST score for both young and elderly subjects. From Figure 5.41, the results show that the average percentages of the RST score were the highest for the green background colour and the lowest for a white background colour for both young and elderly subjects. Furthermore, we observed that the average score for elderly subjects were around half of the young subjects' score.

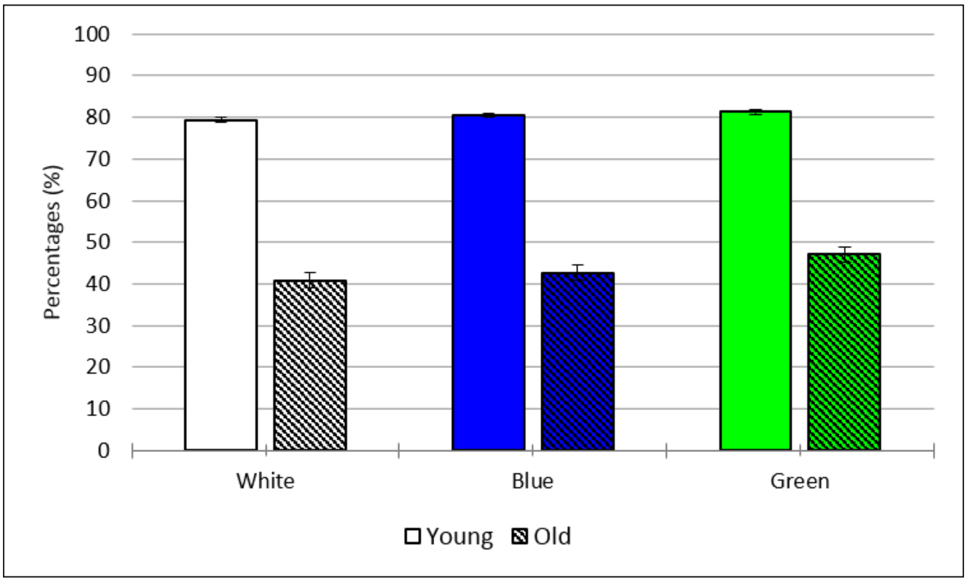


FIGURE 5.41: The process of the RST experiment

To find a significant difference between the average percentages of the RST score for both young and elderly subjects, the t-test statistical analysis (α= 0.05) has been conducted. Table 5.16 summarizes the t-test statistical analysis results. From Table 5.16, the average percentages of the RST score for the young subject is higher than the elderly subject. Furthermore, the t-test statistical analysis stated that there is a significant difference ($p<0.001$) between the average percentages of the RST score of young and elderly subjects.

Table 5.16: The average percentages of the RST score t-test statistical analysis for young and elderly subjects ($\alpha = 0.05$)

RST score	Mean	Variance	t	p
Young	80.3889***	1.0093	28.2673	0.0006
Elderly	43.5294	10.1211		

***$p<0.001$

The authors also analysed variance (ANOVA) test ($\alpha = 0.05$) to examine the significance of differences in the average percentages of RST score among three background colours for both young and elderly subjects. Table 5.17 and Table 5.18 summarizes ANOVA test results for both young and elderly subjects respectively. Based on the results summarized in Table 5.17 and Table 5.18, the ANOVA test results demonstrated that there was no significant difference among three background colours in the average percentages of the RST score for both young and elderly subjects.

Table 5.17: The average percentages of the RST score ANOVA test among three background colours for young subject ($\alpha = 0.05$)

Background colour	Mean	Variance	F	p
White	79.3333	151.2644	0.3087	0.7356
Blue	80.5	210.9483		
Green	81.3333	117.1264		

Table 5.18: The average percentages of the RST score ANOVA test among three background colours for elderly subject (α= 0.05)

Background colour	Mean	Variance	*F*	*p*
White	40.8824	216.3603	2.0994	0.1391
Blue	42.6471	259.7426		
Green	47.0588	328.3088		

The author then conducted a t-test statistical analysis (α= 0.05) on the average percentages of the RST scores for both young and elderly subjects of every background colour with white background colour since white background colour is the commonly used as a screen background colour. Table 5.19 and Table 5.20 shows the summary of t-test statistical analysis conducted on the average percentages of RST score for both young and elderly subjects to determine a significant difference between each background colour with the white background colour.

Table 5.19: The average percentages of the RST score t-test statistical analysis between each background colour with white background colour for young subject (α= 0.05)

Background colour	Mean	Variance	*t*	*p*
White	79.3333	151.2644	-0.4734	0.3197
Blue	80.5	210.9483		
White	79.3333	151.2644	-0.9235	0.1817
Green	81.3333	117.1264		

Table 5.20: The average percentages of the RST score t-test statistical analysis between each background colour with white background colour for elderly subject ($\alpha = 0.05$)

Background colour	Mean	Variance	t	p
White	40.8824	216.3603	-0.6433	0.2646
Blue	42.6471	259.7426		
White	40.8824	216.3603	-1.9876	0.0321
Green	47.0588*	328.3088		

*$p<0.05$

Here, we observed that white background colour has the lowest score for both subject groups. The results from Table 5.19 reveals that the average percentages of the RST score on every background colour have no significant differences between the average percentages of the RST score on a white background colour for the young subject. However, we observed a significant difference ($p<0.05$) on the average percentages of the RST score between white and green background colours for the elderly subject as shown in Table 5.20.

For all 47 subjects, the oxy-Hb concentration changes also which has been recorded by using wearable NIRS system during the experiment will be analysed. For each subject, the values of oxy-Hb concentration changes measured every 0.2[s] were averaged for each background colour for both young and elderly subjects. These values are referred to as average NIRS signal values. Figure 5.42 shows the average NIRS value for each background colour of young and elderly subjects.

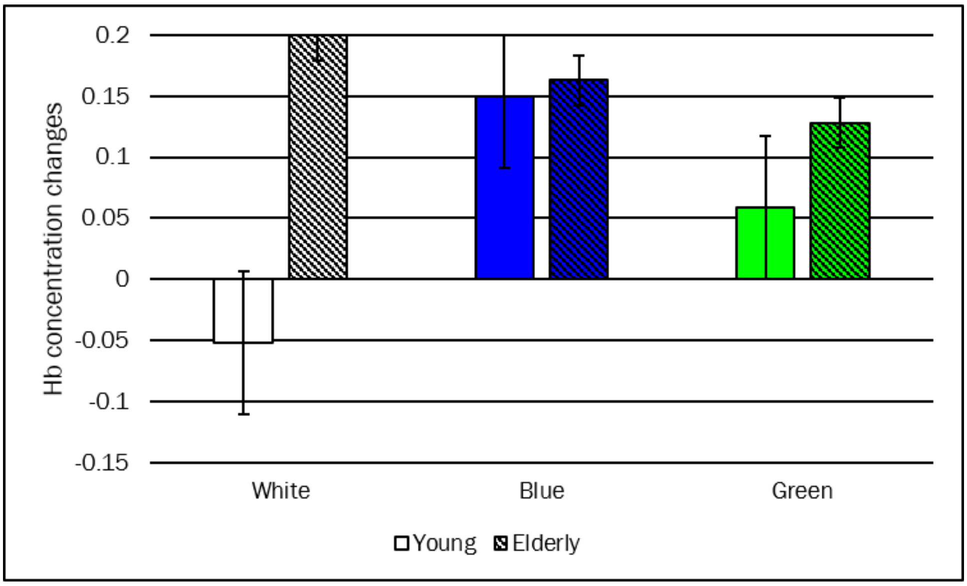


Figure 5.42: The average NIRS value of the RST on three background colours

Figure 5.42 shows that white background colour activated the frontal area of the brain the least for young subject, while white background colour activated the frontal area of the brain the most for elderly subject. To analyse the recorded data in details, we analysed the average NIRS signal values by using t-test statistical analysis (α= 0.05). The overall t-test statistical analysis result between young and elderly subjects was shown in Table 5.21.

Table 5.21: The average NIRS signal value t-test statistical analysis for young and elderly subjects (α= 0.05)

Average NIRS signal value	Mean	Variance	t	p
Young	0.0521	0.0103	-1.5472	0.1309
Elderly	0.1636	0.0013		

Based on Table 5.21, the elderly subject had higher average NIRS value compared to the young subject when performed RST. However, t-test statistical analysis reveals no significant difference between the average NIRS value of young and elderly subjects. Then, we further analysed the data for each background colour since we used three different background colours (white, blue, green) in this experiment. The author conducted a t-test statistical analysis (α= 0.05) on the average NIRS value for both young and elderly subjects of every background colour with the white background colour. Table 5.22 and Table 5.23 shows the summary of ANOVA test statistical analysis conducted on the average NIRS value for both young and elderly subjects to determine a significant difference between background colours.

TABLE 5.22: The average NIRS value ANOVA test among three background colours for young subject (α= 0.05)

Background colour	Mean	Variance	*F*	*p*
White	-0.0522	0.292	1.6535	0.2003
Blue	0.1503	0.2159		
Green	0.0584	0.1979		

TABLE 5.23: The average NIRS value ANOVA test among three background colours for elderly subject (α= 0.05)

Background colour	Mean	Variance	*F*	*p*
White	0.1995	0.1646	0.1502	0.8611
Blue	0.1631	0.1243		
Green	0.1281	0.2516		

Table 5.22 and Table 5.23 stated that the ANOVA test expressed no significant differences for the NIRS signal values between background colours for both young and elderly subjects. Besides, the author conducted a t-test statistical analysis ($\alpha = 0.05$) on the average NIRS value for both young and elderly subjects of every background colour with the white background colour. Table 5.24 and Table 5.25 shows the summary of t-test statistical analysis conducted on the average NIRS value for both young and elderly subjects to determine a significant difference between each background colour with the white background colour.

Table 5.24: The average NIRS signal value t-test statistical analysis between each background colour with white background colour for young subject ($\alpha = 0.05$)

Background colour	Mean	Variance	t	p
White	-0.0522	0.292	-1.899	0.0338
Blue	0.1503*	0.2159		
White	-0.0522	0.292	-0.9549	0.1738
Green	0.0584	0.1979		

$^*p<0.05$

Table 5.25: The average NIRS signal value t-test statistical analysis between each background colour with white background colour for elderly subject ($\alpha = 0.05$)

Background colour	Mean	Variance	t	p
White	0.1995	0.1646	0.2653	0.3971
Blue	0.1631	0.1243		
White	0.1995	0.1646	0.5351	0.3
Green	0.1281	0.2516		

The results from Table 5.24 demonstrates that only the average NIRS signal value between white and blue background colours have a significant difference (p<0.05) for the young subject. On the other hand, Table 5.25 for elderly subject reveals that the average NIRS signal value of white background colour between every background colours did not have any significant differences. Then, we analysed the NIRS signal values in further details by examining the NIRS topography recorded during the experiment. The oxy-Hb topography images data from all subjects were averaged. Figure 5.43 and Figure 5.44 show the oxy-Hb topography images of each background colour for both young and elderly subjects respectively.

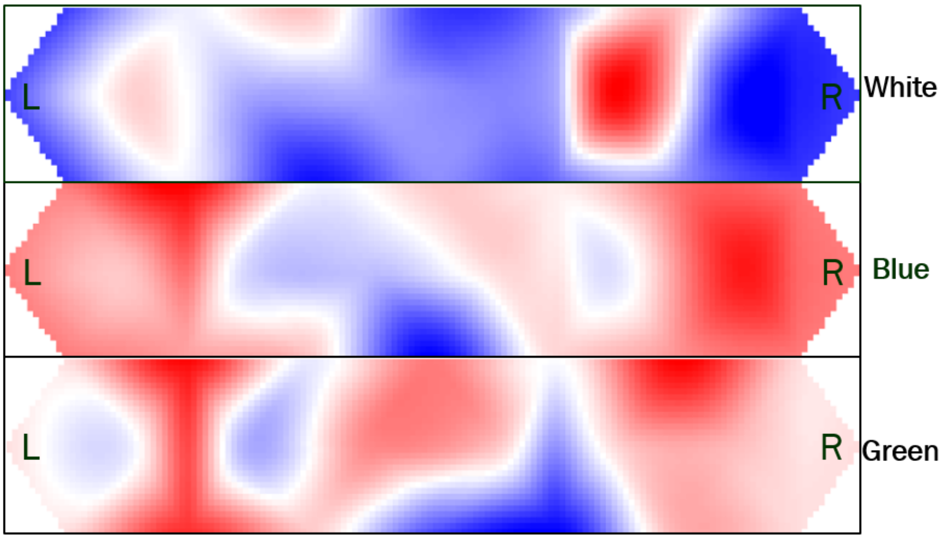


FIGURE 5.43: Average oxy-Hb topography images of RST for young subjects on each background colour

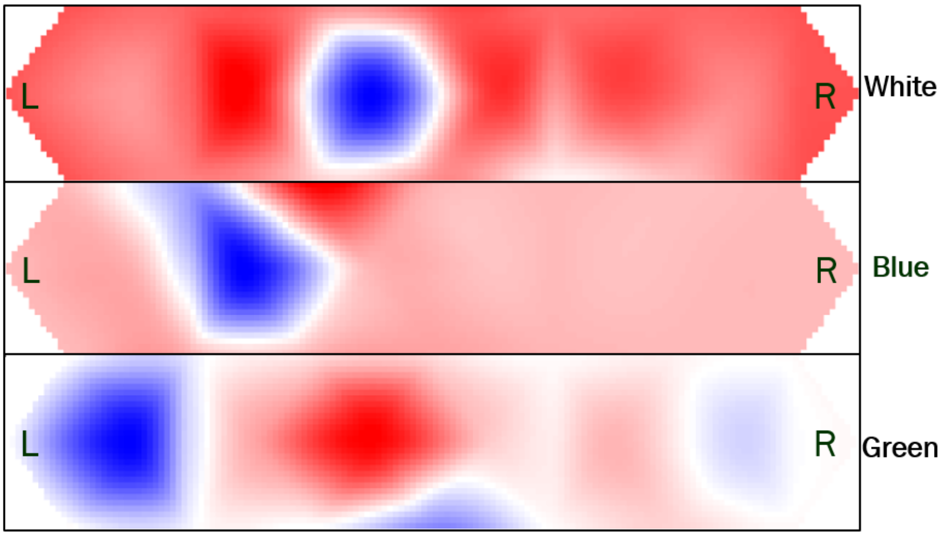


Figure 5.44: Average oxy-Hb topography images of RST for elderly subjects on each background colour

Figure 5.43 and Figure 5.44 show the average oxy-Hb topography images of both young and elderly subjects respectively. Red region represents high activation while blue region represents low activation of the area. From both figures, we observed that white background colour has lower activations on young subjects' frontal area of the brain for RST, while white background colour has higher activations on elderly subjects' frontal area of the brain for RST.

We then analysed the questionnaire answered by subjects right after they finish performed the RST. Figures 5.45 summarize the average value of responses to the questionnaire items answered by both young and elderly subjects for each background colour. The questionnaire asked the subjects to rate their tiredness, readability, difficulty, colour preferences, and concentration levels on a five-point Likert scale. Overall, it may be said that both young and elderly subjects performed the lowest on the white background colour. Interestingly, the NIRS machine displayed a lower rate of changes in oxy-Hb on a white background colour for the young subject, but a higher rate of changes in oxy-Hb for the elderly subject. From questionnaire results, we can understand that both young and elderly subjects had the best visibility on white background colour but they could not concentrate on it, that would make the average percentages of RST score is the lowest.

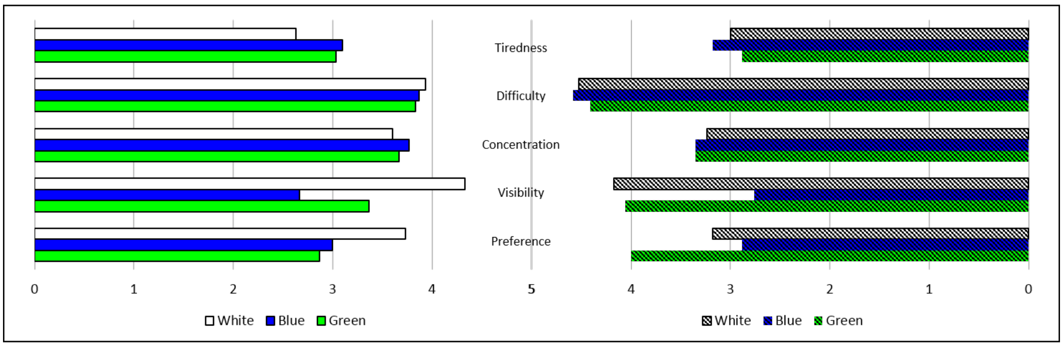


FIGURE 5.45: Questionnaire answered by young subject (left) and elderly subject (right)

5.6 Discussion

In this study, relative changes of blood Hb concentration in the brain were observed by using NIRS system to see the brain function activities of the subjects while they were performing circle counting task (CCT) and reading span task (RST) on different background colours. The oxy-Hb concentration changes in subjects' brains recorded in the NIRS experiment were mapped onto 2D topography images. The images were analysed in relation to the functions of brain regions.

Figure 5.46 and Figure 5.47 show 2D topography images of brain activity that were constructed from NIRS measurement. The figures show typical examples of Hb concentration images created from the Hb measurements while the experiment was conducted. The red region on the topographic results represents higher concentration changes in blood Hb, whereas the blue region represents lower concentration changes, i.e. the red region shows high brain activity and the blue region shows less brain activity or a calm state.

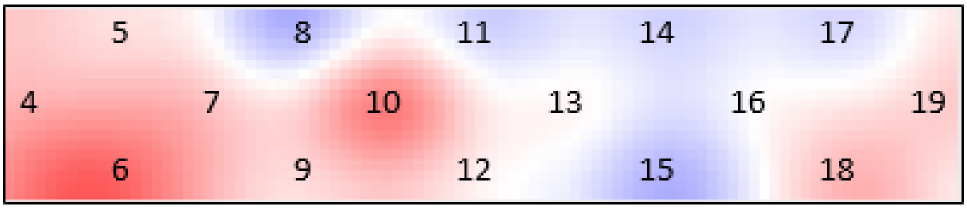


FIGURE 5.46: Typical 2D topography images of brain activity with channel labelled

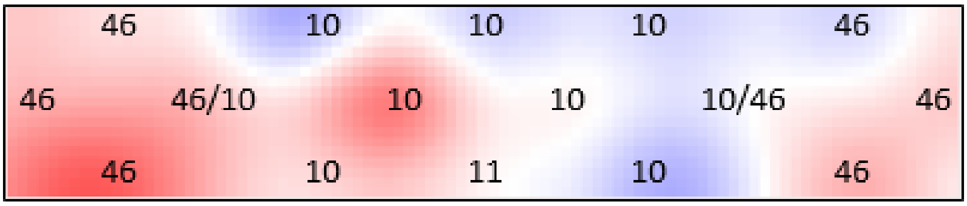


FIGURE 5.47: Typical 2D topography images of brain activity with corresponding Brodmann areas (BA) labelled

5.6.1 CCT on five different background colours

The average percentages score from CCT shows that both young and elderly subjects expressed the same tendency where white background colour has the lowest score in comparison to other background colours. As expected, young subject had a higher score compared to elderly subject. This is because cognitive ability decreasing with age [76]. On the other hand, the results from the NIRS measurement demonstrate that background colours can affect Hb concentrations in the brain where the CCT on white background colour activated both young and elderly subjects' frontal area of the brain the most.

The results from the subjects when performing the CCT with white background colour showed that the front polar region in the brain tended to experience higher levels of change in Hb concentration. BA 10, which located at the frontal part of the brain, exhibited that oxy-Hb concentration changes tended to increase more right after when both young and elderly subjects starting to perform CCT on the white background colour. Even though the Hb concentration changes were higher for white background colour compared to other background colours, the averaged percentages CCT score suggest that white has the lowest score among other background colours for both young and elderly subjects.

The results suggested that white background colour provokes states that require more eye movements. BA 10, which locates at the frontal areas of the brain, has been proposed that not only related to memory, but also play a major role in the highest level of integration of information coming from visual [77][78]. Thus, it can be said that it has related to eye movements that showed a higher concentration of Hb changes. These results finding correlated with the results in the study by Yamazaki *et al.*, which expressed the same reason [19][45][79].

This indicates that eye movements tended to be more active due to high contrast between font and background colour and distract the focus and concentration level of subjects' brain while subjects performing CCT on white background colour [80][81]. From questionnaire results, we can understand that young subject felt least tired and can concentrate the most on white background colour even though the average percentages of CCT score is the lowest. However, the elderly subject stated that they felt most tired and can be considered as stress when performing the task on white background colour which affected higher average NIRS value.

5.6.2 RST on five different background colours

The RST score average percentages of the young subject shows that yellow background colour had the highest score and the lowest score is the red background colour. However, the NIRS measurement result demonstrated that RST on red background colour activated on young subjects' frontal area of the brain. The same tendency also has been observed from the elderly subject. However, elderly subjects score the highest for RST on white background colour which is full score and the lowest on the yellow background colour. The NIRS measurement result exhibited that RST on yellow background colour activated elderly subjects' frontal area of the brain.

There is not so much difference for the average percentages score between young and elderly subjects even though the performance is better for the elderly subject. Besides, even though young subject's frontal area of the brain activated more than the elderly, both subjects' brain seemed to relax while performing RST with five background colours.

The results from the young subjects when performing the RST with red background colour showed that the front polar region in the brain tended to experience higher levels of change in Hb concentration. BA 11 at frontal area exhibited that oxy-Hb concentration changes tended to increase more right after when young subject starting to perform RST on the red background colour. Even though the Hb concentration changes were higher for red background colour, the averaged percentages RST score suggest that red has the lowest score among other background colours for young. This is because, more than 80% of young subject is male and red always has been said that gives negative influence to male. Therefore, red background colour enhanced cognitive load in young male subject [82]. Thus, red background colour might impede task performance of young subject in overall [83].

These results have the same tendency for elderly subject too. However, instead of red background colour, the elderly subject experienced the same thing on the yellow background colour which has the lowest score on RST with higher oxy-Hb concentration changes. BA 10 at the frontal area has related to memory. Christof stated that red and yellow are better for memory [84]. In terms of the average percentage score, our results showed the coincide results for yellow, but the contradicts result for red. Unlike young subject, there is not more than 60% of the elderly subject is male. The negative influence of red background colour effect might not affected elderly subject in overall [83].

White background colour might have the best score for the elderly subject, but their brain were less activated. Less activation of brain function may not good in terms of working memory since our brain needs a certain amount of stress to develop its functions more [85]. Moreover, the average percentages of RST have a rather high score for both young and elderly subjects and did not show any differences between other background colours, the author suspected that the RST provided was too easy.

5.6.3 RST on three different background colours

Overall, it may be said that RST with three background colours show more explicit results than RST with five background colours. Both young and elderly subjects performed the lowest on white background colour. A comparison of both groups' results showed the same tendency in terms of performance for each background colour. Because of the deterioration in their abilities, the elderly group scored much lower for performance [86]. The scores displayed the same tendency as those in Yamazaki's study and suggest that bluish background colours could elicit better scores for performance than could whitish background colours [19][21].

However, this study's results contradict those of RST with five different background colours study, which had confirmed the white background's producing the best scores for elderly subject because the RST used in the previous experiment had been relatively easier and had not produced any differences, among the colours. From these results, we understand that elderly people express greater transposition than do younger people in terms of performance when exposed to different background colours. Interestingly, NIRS machine displayed lower rate of changes in oxy-Hb on white background colour for young subject, but higher rate of changes in oxy-Hb for elderly subject. The results from the young subjects when performed the RST with white background colour showed that the front polar region in the brain tended to experience lower levels of change in Hb concentration. A greater contrast between the background colour and the black font text increased the changes in the Hb concentration in the brains of the elderly subject but not of the young subject.

Working memory is known to be located in the frontal areas of the brain. Most channels covered BA 10, which involved in working memory in the frontal areas show high Hb concentration changes for both the young and elderly subjects against a blue background. We suggest that a bluish background may be better for memory retrieval. This suggestion is supported by Anna's study, which found that exposure to blue light led to greater functional responses within the brain's prefrontal cortex during a task that required the use of working memory [87].

BA46 in the younger subjects exhibited the least activity for the white background. BA46 plays a role in sustaining attention and managing the working memory. These results are supported by Hall and Hanna, who suggest that, even though greater contrast ratios between the background and font colours lead to better readability, subjects concentrate the least and perform the lowest for a white background [88]. The questionnaires answered by the younger subjects returned proportional results that indicated that even though the white background offered the best visibility, they had the least concentration. The elderly subjects gave the same responses.

However, BA46 in the elderly subjects had been more highly activated than in the younger subjects when the former group performed against the white background. BA46 in the elderly subjects had also been activated by the blue and green backgrounds. We believe that the elderly subjects were not as accustomed to using mobile devices as were the younger subjects, so the former group may have felt a greater cognitive burden when concentrating on the tasks [82]. The higher activations of the brain functions could be assumed to indicate greater stress being placed on the brain functions.

5.7 Conclusion

In conclusion, this chapter discussed the background colours effect on subjects' brain while they performing the task. Thus, the following points are provided:

- The young subject has a higher score than elderly subject on CCT. Both subjects performed the best on yellow, while the least on the white background colour. In terms of brain activity, young subject's brain activated more than elderly subject's brain while performing CCT. When comparing background colour, both subjects' brain activated the most on white compared to other background colours.
- The elderly subject has a higher score than young subject on RST with five background colours, even though the score for the two groups are not much difference. The elderly subject performed the best on white, while the least on

the yellow background colour. However, the young subject performed the best on yellow compared to other background colours. In terms of brain activity, although young subject's brain activated more than the elderly, both subjects' brain seemed to relax while performing RST with five background colours. When comparing background colour, the elderly subject's brain activated the most on yellow, while young subject's brain activated the most on the red background colour. Both subject groups' brain are in the state of calm when performed RST on the white background colour.

- The young subject has a higher score than elderly subject on RST with three background colours. Both subjects performed the best on the green, while the least on the white background colour. In terms of brain activity, the elderly subject's brain activated more than young subject's brain while performing RST with three background colours. When comparing background colour, elderly subjects' brain activated the most on white, while young subject's brain is the calmest on white.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

This study discussed the analyses on brain functions for effective communications. Chapter 2 unveiled the functions of the brain depends on the region. Besides, Chapter 3 introduced the brain imaging technique that we used in this study. Chapter 4 and Chapter 5 demonstrated the cognitive tasks experiments in the details. In Chapter 4, the study presented a language sound-induced with emotions effect on brain functions. Besides, in Chapter 5, the study described the effect of different screen background colour on brain functions.

In this study, we focused on the language areas to see the effect of emotional context on it. The author described that emotional context might not preferable for new language learning, but emotional context could give an effect on working memory and emotion, which are known to be essential to communication in case of familiar language. We can conclude that emotional context might not suitable to understand a new language, but it can enhance working memory and emotion processes, by understanding the emotion intended in an unfamiliar language. We speculate that this may be because of too much emotion could be a distraction for listeners and could divert their concentration away from language processing.

On the other hand, we can conclude that emotional context is essential in good communication when involving languages that the listeners are familiar with. We also found out that sentences with emotional context encourage working memory performance and the ability to retain information over short delays. Since we reversed the original sentences, the meaning of the sentence is not understandable. Therefore, we considered the sentences as babble or gibberish like a baby language. To obtain a higher degree of success in communication for a familiar language, emotions play an important role. This is because, if the emotions are successfully conveyed, the language areas also might be activated.

Also, in this study, the effects of background colour on brain functions of young and elderly people were examined. The author expressed that both of subjects group performed the worst on white background colour circle counting task (CCT). However, white background colour activates a frontal region of the brain for both subject groups. Therefore, a combination of black text and white background colour might not consider as the preferable background colour for improving users' performance. However, higher contrast might require more eye movements, thus could activates more the frontal area of the brain as CCT is focus more on concentration.

Besides, the reading span task (RST) score showed that bluish background colours had better score compared to white background colour in performance. However, white background colour activated elderly subjects' frontal area of the brain. Less activation on brain functions may not good since our brain needs a certain amount of stress to develop its functions more. Since the CCT requires attention, the effect of the background colours on the brain functions may be different from the RST, which focuses more on working memory.

6.2 Future works

In addition to this dissertation, several improvements are possible to contribute to effective communication. Furthermore, this study's results might only affect people with native Japanese language, because all the subjects used in this study were native Japanese. In case of application the study's results in the dementia field, to directly apply this study's results may not be suitable as it was conducted on young and healthy subjects. While symptoms of dementia can vary greatly, in the future, we aim to study the brain reaction of older subjects with dementia tendencies to gain more accurate results.

Since the research on human-robot interaction has already begun with the use of NIRS as a tool. It is not impossible to further this study from human-human communication to human-robot communication. In our future work, other aspects of human languages should be taken into account, since different languages could have different intonations of the emotions that play an important role in achieving better human-human communication, as well as human-robot communication.

It is important to investigate in details regarding working memory. Therefore, in the next study, the author plan to conduct experiments related to working memory. This time, the study will be focused on elderly people, who have memory loss and language impairment. The authors also will consider the hue, brightness, and contrast of the background colours and font for the different effect of background colours on brain function. Last but not least, it is important to increase the number of subjects in the next study to obtain a more general sampling, since brain functions are known to vary among individuals.

6.2.1 Contributions

In summary, this dissertation provides the following for possible contributions in the future:

1. It is hoped that this study's results can be used as a base for language learning as we found that emotional context impedes the activation of the language areas of the brain in case of new language sound.
2. By applying this study's results, we can hopefully find suitable ways to effectively communicate with those people who have communication disability such as dementia patients who have deterioration in language comprehension

in case of familiar language. The emotion conveyed messages could activate their language areas of the brain. in case of familiar language.

3. 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.

4. The study's results could be a key in the results being utilised in therapy for controlling the rate of mental decline as we found that a white background colours may excite the brain for memory retrieval and concentration. Thus, it can help to improve effective communication by control the rate of mental ability deterioration.

5. As bluish background colour could boost users' performance, we hope that the results of this study could be a guide in designing suitable information and communication technology and cognitive interfaces and devices for people.

Appendix A

List of Publications

A.1 International journal paper

[J.1] Muhammad Nur Adilin Mohd Anuardi, Atsuko K. Yamazaki, 2019 ”Effect of emotionally toned Malay language sounds on the brain: a NIRS analysis” *International Journal on Perceptive and Cognitive Computing* Vol. 5, No. 1, pp. 1-7, 2019. `https://doi.org/10.31436/ijpcc.v5i1.72`

[J.2] Muhammad Nur Adilin Mohd Anuardi, Atsuko K. Yamazaki, 2019 ”Effects of emotionally induced language sounds on brain activations for communication” *Artificial Life and Robotics* Vol. 24, No. 3, pp. 312-317, 2019. `https://doi.org/10.1007/s10015-019-00529-x`

A.2 International conference papers (peer-reviewed)

[C.1] Muhammad Nur Adilin Mohd Anuardi, Atsuko K. Yamazaki. ”A NIRS Study of Different Colour Effects on Short Memory Tasks Between Young and Elderly Subjects” *KES International Conference on Innovation in Medicine and Healthcare (KES-InMed-19)*, vol. 145, pp. 205-209. Springer, 2019. `https://doi.org/10.1007/978-981-13-8566-7_20`

[C.2] Atsuko K.Yamazaki, Noriaki Miwa, Kazukiyo Inada, Muhammad Nur Adilin Mohd Anuardi, Mashu Sanjo. "Effects of facial expressions on impression evaluation for Japanese stuttering voices" *International Conference on Knowledge-Based and Intelligent Information & Engineering Systems (KES 2018)*, vol. 126, pp. 1360-1367. Elsevier, 2018. `https://doi.org/10.1016/j.procs.2018.08.087`

[C.3] Muhammad Nur Adilin Mohd Anuardi, Atsuko K.Yamazaki, Kaoru Eto. "A Pre-Analysis of the Effect of White, Blue and Green Background Colours on Working Memory in a Reading Span Task" *International Conference on Knowledge-Based and Intelligent Information & Engineering Systems (KES 2018)*, vol. 126, pp. 1847-1854. Elsevier, 2018. `https://doi.org/10.1016/j.procs.2018.08.092`

[C.4] Muhammad Nur Adilin Mohd Anuardi, Atsuko K. Yamazaki. "A pre-NIRS study of white, blue, and green background colour effects on working memory" *South East Asian Technical University Consortium (SEATUC 2018)*, 2018.

[C.5] Muhammad Nur Adilin Mohd Anuardi, Atsuko K.Yamazaki, Kaoru Eto. "A pre-NIRS study of background colour effects on the functions of the frontal lobe" *International Conference on Knowledge-Based and Intelligent Information & Engineering Systems (KES 2017)*, vol. 112, pp. 2031-2039, Elsevier, 2017. `https://doi.org/10.1016/j.procs.2017.08.149`

Appendix B

Related Data

List of sentences for reading span task:

母親は、封筒の名前を初めて見たときひどくびっくりした。

人間は氷期と間氷期を何度も経て、ゆっくりと進歩してきた。

その技術のレベルはしろうとの域をはるかに越えている。

子どもはみやげの紙袋の口を開けてみてびっくりした。

老人はわたしを隣に座らせ、風変わりな話を聞かせてくれた。

小道ぞいに村をぬけ、丘を上ると、海を見下ろすがけに出た。

その男は会議で弁舌をふるって警告を発した。

少年は、すべるように空を飛んで行く一羽のかもめを見た。

さまざまな工夫をこらして、西洋のことばを学ぼうとした。

彼等は毎日歌の練習をしています。

この町には小さな公園がいくつもある。

私は桜の咲く４月が好きです。

年末には家族で大掃除をします。

突然雷が鳴ったので、驚いて皿を落とした。

私はぶどうよりもなしが好きだ。

父は生まれた故郷に帰りたいと言った。

私はバスで学校に通っています。

日曜日は一日中お父さんと遊びました。

今日は朝からみんなで体操をしました。

そのスーパーは彼の家のすぐ近くにあります。

毎年あの店では花見の季節に、無料でござを貸し出している。

雨のしずくで渇きを癒しながら、密林を１週間さまよい続けた。

その子供は洋服に食べ物を落としてしみをつけた。

横断歩道は車が通るための道です。

定規は長さを測るための道具です。

木曜日は水曜日の次の日です。

野菜は海の中で収穫されます。

電車に乗り遅れたので母に車で送ってもらった。

彼はぶっきらぼうだが、根はいいやつだと思う。

公園で昼寝をしていたら、大きな蜂に刺された。

物事に対する自分の心の動きに注意深く目を向けよう。

それは、ゆれながら水銀のように光って上に上がった。

二人の子供が、青い湖のそばで遊んでいた。

祖母は黙って家の外を眺めるような目つきをしていた。

ドライアイスは冷凍食品を冷やすのにちょうどよい。

この色は実際は桜の皮から取り出した色なのだった。

上の面や横の面は、青く黒く金属のように見える。

これは現在世界で起こっている出来事と同じである。

野球が初めて日本に伝えられたのは明治５年ごろである。

一番下の弟が、まぶしそうに目を動かしながら尋ねた。

彼は、人々の信頼に答えようと、昼も夜も働いた。

農民たちは稲も麦も豊かに実ってくれるものと期待した。

彼はかぜをひいて下宿で寝ていたが、知らせを聞いてはね起きた。

その子供は目を丸くして、分からないという表情をした。

地上に降った雨は海へ流れてゆくが、雪は降り積もる。

文法が分かるからといって、英語が通じるとは限らない。

父が娘あての手紙に、しっかり勉強するようによ書いた。

彼も、科学的な調査の結果を見せられては、反論できなかった。

厳しい寒さの中を、私は２０年ぶりに故郷へと帰った。

用語の中には、漢字で日本語に訳されているものもある。

妹が帰ってくれる日、私と弟は家庭菜園のかぼちゃを全部収穫した。

私たちは、日ごろさまざまな問題に出会う。

葉書きには紙いっぱいはみ出すほどの、威勢の良いマルが書かれた。

教師は一人一人の独自な意見が出せるような話題を選んだ。

私は話を聞いて、体が一瞬ゆらぐような不思議な感じに襲われた。

大きなえびがたくさん並んでいるのが見えていた。

彼は５年生のときから天気予報の記録をずっととっている。

警官が広場中に聞こえるような甲高い声で叫んだ。

私が長い間家族と住んでいた家はもう取り壊されていた。

その学生は一週間に、少なくとも二冊の本を読む習慣をつけた。

聞き手は、相手の話の内容を知りたいと思って耳を傾ける。

日本語学習人口は百万人を超えるに至ったと推定されている。

私は写真を輪ゴムで束ね、しばらく保存していた。

追いつめられた人たちは、一通の要求書を彼のところに持ってきた。

ある人から鈴をもらい、私はそれを椅子にぶら下げた。

父親は東京から子供たちに菓子を持って帰った。

気がつくとボートは、浜辺に打ち上げられていた。

死んだ父親は筆まめな人で、頻繁に手紙をよこした。

転校生は彼女と目があったとたんに、友達になれそうだなと思った。

その人は美しい色の糸で織った着物を見せてくれた。

少女がそこで見たのは、信じられないような事件だった。

近くの駅からその町の駅までは、特急でおよそ３時間かかる。

そのパイロットは昔から真夜中に星空を眺めるのが好きだった。

彼はその日から、道のでこぼこを通るのが楽しみとなった。

舟乗りは子猫を丘の上の自分の家に連れて帰った。

子供たちは、とても月が明るいのでみんなで外へ出かけた。

祖父ひと月後に、永遠にまぶたを閉じたのである。

この時突然、私の脳裏に子供の頃の光景が浮かんできた。

その日は、久しぶりに朝から夕方まで雨が降り続いた。

昼食をとった後、私はぶらぶらとその辺を散歩した。

茶の間に座っていた父は、はだしで表へ飛び出した。

降りしきる雨に、池の堤防はもろくもくずれた。

世界には、2000以上の言語があると言われている。

彼には妻はなく、内気な妹と二人で暮らしている。

その朝早く、私はわが家の門の前に立っていた。

その日は、山小屋には羊飼いも誰も来ていなかった。

彼はゆっくりと白い自転車を走らせて運動場を回った。

男は今日は海に出るのはよした方がいいとその子に注意した。

日本について学ぼうとする外国人の存在は貴重である。

小学生たちは、元気に夏休みの一日一日を過ごしていた。

突然の知らせに二人は声も出ず、座り込んでしまった。

夫が車椅子に乗るようになってから、１２年が過ぎた。

Questionnaire for Malay and reversed Japanese language sounds with five emotions:

被験者番号＃＿＿＿＿

この度は実験にご協力していただき誠にありがとうございました。以下のアンケートにご回答いただければ幸いです。５段階評価の箇所では、次の回答例を参考にしてください。

（回答例）当てはまる数字に○をつけてください。

１．非常に安い
２．やや安い
３．どちらともいえない
４．やや高い
５．大変高い

［１］この課題を行なって疲れましたか。

１．全く疲れなかった
２．あまり疲れなかった
３．どちらともいえない
４．やや疲れた
５．大変疲れた

［２］この課題は難しかったですか。

１．非常に簡単だった
２．やや簡単だった
３．どちらともいえない
４．やや難しかった
５．非常に難しかった

［３］この課題に集中して取り組めましたか。

１．全く集中できなかった
２．あまり集中できなかった
３．どちらともいえない
４．やや集中できた
５．大変集中できた

［４］この課題の画面は見やすかったですか。

１．大変見にくかった
２．やや見にくかった
３．どちらともいえない
４．やや見やすかった
５．非常に見やすかった

［５］この課題の画面の色は好きですか。

１．非常に嫌い
２．やや嫌い
３．どちらともいえない
４．やや好き
５．非常に好き

【自由記述】その他、実験の説明、設定、実地、実験で用いた課題などについて、気が付いた点やご意見がございましたら、ご自由にお書きください。

Questionnaire for reversed Japanese language sound with three emotions:

年齢：　　　　　　　　　　　　性別：男・女

1. この文を聞いたとき、話者の本当の気持ちを表しているのは次のうちどれですか。

A. 喜び　B. 悲しみ　C. 怒り　D. 恐怖　E. 驚き　F. 非感情

2. この文を聞いたとき、話者の本当の気持ちを表しているのは次のうちどれですか。

A. 喜び　B. 悲しみ　C. 怒り　D. 恐怖　E. 驚き　F. 非感情

3. この文を聞いたとき、話者の本当の気持ちを表しているのは次のうちどれですか。

A. 喜び　B. 悲しみ　C. 怒り　D. 恐怖　E. 驚き　F. 非感情

Questionnaire for circle counting task and reading span task on different background colours:

年齢：　　　　　　　　性別：男・女

1. この文を聞いたとき、話者の本当の気持ちを表しているのは次のうちどれですか。

A. 喜び　B. 悲しみ　C. 怒り　D. 恐怖　E. 驚き

2. この文を聞いたとき、話者の本当の気持ちを表しているのは次のうちどれですか。

A. 喜び　B. 悲しみ　C. 怒り　D. 恐怖　E. 驚き

3. この文を聞いたとき、話者の本当の気持ちを表しているのは次のうちどれですか。

A. 喜び　B. 悲しみ　C. 怒り　D. 恐怖　E. 驚き

4. この文を聞いたとき、話者の本当の気持ちを表しているのは次のうちどれですか。

A. 喜び　B. 悲しみ　C. 怒り　D. 恐怖　E. 驚き

5. この文を聞いたとき、話者の本当の気持ちを表しているのは次のうちどれですか。

A. 喜び　B. 悲しみ　C. 怒り　D. 恐怖　E. 驚き

Appendix C

Awards

[A.1] Grants for Non-Japanese researchers by The NEC C&C Foundation ”A brain study to investigate the effect of ICT terminal background colour on the working memory of the elderly”

Bibliography

[1] Kuniyoshi L Sakai. *Map of Language Area of the Brain.* Meiji Shoin, 2009.

[2] Ann Blandford. Hci for health and wellbeing: challenges and opportunities. *International Journal of Human-Computer Studies*, 2019.

[3] Myounghoon Jeon, Rebecca Fiebrink, Ernest A Edmonds, and Damith Herath. From rituals to magic: Interactive art and hci of the past, present, and future. *International Journal of Human-Computer Studies*, 2019.

[4] Francisco Gutiérrez, Nyi Nyi Htun, Florian Schlenz, Aikaterini Kasimati, and Katrien Verbert. A review of visualisations in agricultural decision support systems: An hci perspective. *Computers and Electronics in Agriculture*, 163:104844, 2019.

[5] Fernando Suárez-Warden, Salvador Barrera, and Leticia Neira. Communicative learning for activity with students aided by augmented reality within a real time group hci. *Procedia Computer Science*, 75:226–232, 2015.

[6] Cecil R Reynolds and Elaine Fletcher-Janzen. *Encyclopedia of special education: A reference for the education of children, adolescents, and adults with disabilities and other exceptional individuals*, volume 3. John Wiley & Sons, 2007.

[7] Ping Zhou, M Shamim Hossain, Xiaofen Zong, Ghulam Muhammad, Syed Umar Amin, and Iztok Humar. Multi-task emotion communication system with dynamic resource allocations. *Information Fusion*, 52:167–174, 2019.

[8] Berna A Uzundag and Aylin C Küntay. Children's referential communication skills: The role of cognitive abilities and adult models of speech. *Journal of experimental child psychology*, 172:73–95, 2018.

[9] Tina J Jayroe and Dietmar Wolfram. Internet searching, tablet technology and older adults. *Proceedings of the American Society for Information Science and Technology*, 49(1):1–3, 2012.

[10] Tobias Brosch, Gilles Pourtois, David Sander, and Patrik Vuilleumier. Additive effects of emotional, endogenous, and exogenous attention: behavioral and electrophysiological evidence. *Neuropsychologia*, 49(7):1779–1787, 2011.

[11] Arne Öhman, Daniel Lundqvist, and Francisco Esteves. The face in the crowd revisited: a threat advantage with schematic stimuli. *Journal of personality and social psychology*, 80(3):381, 2001.

[12] Laura Jimenez-Ortega, Manuel Martín-Loeches, Pilar Casado, Alejandra Sel, Sabela Fondevila, Pilar Herreros De Tejada, Annekathrin Schacht, and Werner Sommer. How the emotional content of discourse affects language comprehension. *PLoS One*, 7(3):e33718, 2012.

[13] Ruth Filik, Christian Mark Hunter, and Hartmut Leuthold. When language gets emotional: Irony and the embodiment of affect in discourse. *Acta Psychologica*, 156:114–125, 2015.

[14] Aya Ihara, Qiang Wei, Ayumu Matani, Norio Fujimaki, Haruko Yagura, Takeshi Nogai, Hiroaki Umehara, and Tsutomu Murata. Language comprehension dependent on emotional context: A magnetoencephalography study. *Neuroscience research*, 72(1):50–58, 2012.

[15] KGD Tharangie, CMA Irfan, CA Marasinghe, and Koichi Yamada. Kansei engineering assessing system to enhance the usability in e-learning web interfaces: Colour basis. In *16th International Conference on Computers in Education*, volume 1, pages 145–150, 2008.

[16] Young Gun Jang, Hack Yoon Kim, and MK Yi. A color contrast algorithm for e-learning standard. *International Journal of Computer Science and Network Security*, 7(4):195–201, 2007.

[17] Ravi Mehta and Rui Juliet Zhu. Blue or red? exploring the effect of color on cognitive task performances. *Science*, 323(5918):1226–1229, 2009.

[18] Micaela Y Chan, Sara Haber, Linda M Drew, and Denise C Park. Training older adults to use tablet computers: does it enhance cognitive function? *The Gerontologist*, 56(3):475–484, 2014.

[19] Atsuko K Yamazaki and Kaoru Eto. A preliminary experiment to investigate the effects of blue backgrounds on a tablet screen for elderly people. *Procedia computer science*, 60:1490–1496, 2015.

[20] Chris Racey, Anna Franklin, and Chris M Bird. The processing of color preference in the brain. *NeuroImage*, 191:529–536, 2019.

[21] Atsuko K Yamazaki. An analysis of background-color effects on the scores of a computer-based english test. In *International Conference on Knowledge-Based and Intelligent Information and Engineering Systems*, pages 630–636. Springer, 2010.

[22] Muhammad Mansoor Azeem, Jamshed Iqbal, Pekka Toivanen, and Abdul Samad. Emotions in robots. In *International Multi Topic Conference*, pages 144–153. Springer, 2012.

[23] Rosalind W Picard. *Affective computing.* MIT press, 2000.

[24] Javier G Rázuri, David Sundgren, Rahim Rahmani, Antonio Moran, Isis Bonet, and Aron Larsson. Speech emotion recognition in emotional feedbackfor human-robot interaction. *International Journal of Advanced Research in Artificial Intelligence (IJARAI)*, 4(2):20–27, 2015.

[25] Nobuyoshi Matsumoto, Hiroyuki Fujii, and Michio Okada. Minimal design for human–agent communication. *Artificial Life and Robotics*, 10(1):49–54, 2006.

[26] Ryohei Nakatsu. Communications, artificial life, and art. *Artificial Life and Robotics*, 3(3):190–196, 1999.

[27] Takanori Shibata, Kazuya Ohkawa, and Kazuo Tanie. Spontaneous behavior for cooperation through interaction: an emotionally intelligent robot system. *Artificial Life and Robotics*, 1(3):105–109, 1997.

[28] Kanu Boku, Taro Asada, Yasunari Yoshitomi, and Masayoshi Tabuse. Speech synthesis of emotions using vowel features of a speaker. *Artificial Life and Robotics*, 19(1):27–32, 2014.

[29] Hedian Jin, Chunguang Li, and Jiacheng Xu. Pilot study on gait classification using fnirs signals. *Computational intelligence and neuroscience*, 2018, 2018.

[30] Mohammad Wasay, Wolfgang Grisold, William Carroll, and Raad Shakir. World brain day 2016: celebrating brain health in an ageing population. *The Lancet Neurology*, 15(10):1008, 2016.

[31] Wai Kwong Tang, Eric Wong, Helen FK Chiu, CM Lum, and Gabor S Ungvari. The geriatric depression scale should be shortened: results of rasch analysis. *International journal of geriatric psychiatry*, 20(8):783–789, 2005.

[32] Nikki L Hill, Caroline McDermott, Jacqueline Mogle, Elizabeth Munoz, Nicole DePasquale, Rachel Wion, and Emily Whitaker. Subjective cognitive impairment and quality of life: a systematic review. *International psychogeriatrics*, 29(12):1965–1977, 2017.

[33] Kuniyoshi L Sakai, Arihito Nauchi, Yoshinori Tatsuno, Kazuyoshi Hirano, Yukimasa Muraishi, Masakazu Kimura, Mike Bostwick, and Noriaki Yusa. Distinct roles of left inferior frontal regions that explain individual differences in second language acquisition. *Human brain mapping*, 30(8):2440–2452, 2009.

[34] Adele Diamond. Executive functions. *Annual review of psychology*, 64:135–168, 2013.

[35] Akira Miyake and Naomi P Friedman. The nature and organization of individual differences in executive functions: Four general conclusions. *Current directions in psychological science*, 21(1):8–14, 2012.

[36] Chin-Chiuan Lin. Effects of contrast ratio and text color on visual performance with tft-lcd. *International Journal of Industrial Ergonomics*, 31(2):65–72, 2003.

[37] S Saburi. Structure of visibility for the combination of background and character colors: an analysis by a maximum likelihood asymmetric multidimensional scaling. *The Japanese Journal of Behavior Metrics*, 35(2):193–201, 2008.

[38] Stephen Frey and Michael Petrides. Orbitofrontal cortex: A key prefrontal region for encoding information. *Proceedings of the National Academy of Sciences*, 97(15):8723–8727, 2000.

[39] Masato Fukuda. Clinical interpretation of nirs wave shapes, 2011.

[40] Matsuda Yasuhiro and Ono Yumie. Non-invasive biosignal processing and analysis-v. *Systems, Control and Information*, 62(10):435–440, 2018.

[41] Frans F Jobsis. Noninvasive, infrared monitoring of cerebral and myocardial oxygen sufficiency and circulatory parameters. *Science*, 198(4323):1264–1267, 1977.

[42] HR Heekeren, Hellmuth Obrig, R Wenzel, K Eberle, J Ruben, Kersten Villringer, R Kurth, and Arno Villringer. Cerebral haemoglobin oxygenation during sustained visual stimulation–a near–infrared spectroscopy study. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, 352(1354):743–750, 1997.

[43] JH Meek, CE Elwell, MJ Khan, J Romaya, JS Wyatt, David Thomas Delpy, and Semir Zeki. Regional changes in cerebral haemodynamics as a result of a visual stimulus measured by near infrared spectroscopy. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 261(1362):351–356, 1995.

[44] J Ruben, R Wenzel, Hellmuth Obrig, Kersten Villringer, J Bernarding, C Hirth, H Heekeren, U Dirnagl, and Arno Villringer. Haemoglobin oxygenation changes during visual stimulation in the occipital cortex. In *Oxygen Transport to Tissue XIX*, pages 181–187. Springer, 1997.

[45] Atsuko Yamazaki and Kaoru Eto. An analysis of white and blue background-color effects on the scores of web-based english grammar tests using near-infrared spectroscopy. In *Frontiers in Artificial Intelligence and Applications*, pages 911–920. 2012.

[46] Noriyuki Oka, Toshiyuki Sugimachi, Kouji Yamamoto, Hideki Yazawa, Hideki Takahashi, Jongseong Gwak, and Yoshihiro Suda. Impact of auditory alert on driving behavior and prefrontal cortex response in a tunnel: An actual car driving study. In *International Conference on Applied Human Factors and Ergonomics*, pages 373–382. Springer, 2019.

[47] Sachiyo Ozawa, Noriaki Kanayama, and Kazuo Hiraki. Emotion-related cerebral blood flow changes in the ventral medial prefrontal cortex: An nirs study. *Brain and cognition*, 134:21–28, 2019.

[48] Débora Cañizo, Stephanie Hadley, Marta Camprubí, Javier Rodriguez-Fanjul, and Joan Sanchez-de Toledo. 264: Combining nirs, aeeg, and neuromarkers to assess brain damage in pediatric cardiac surgery. *Critical Care Medicine*, 47(1):113, 2019.

[49] Michael Hall, Ujwal Chaudhary, Gustavo Rey, and Anuradha Godavarty. Temporal mapping and connectivity using nirs for language-related tasks. In *Biomedical Optics*, pages BTu3A–58. Optical Society of America, 2012.

[50] Takayuki Kodama, Shin Murata, Jun Murata, and Shinichi Tanaka. Changes of cerebral oxygenation by near-infrared spectroscopy during the reading span test in community-dwelling elderly. *Journal of Physical Therapy Science*, 24(1):21–24, 2009.

[51] Annett Schirmer and Sonja A Kotz. Beyond the right hemisphere: brain mechanisms mediating vocal emotional processing. *Trends in cognitive sciences*, 10(1):24–30, 2006.

[52] Victoria Fromkin, Robert Rodman, and Nina Hyams. *An introduction to language*. Cengage Learning, 2018.

[53] Stephanie Sutoko, Hiroki Sato, Atsushi Maki, Masashi Kiguchi, Yukiko Hirabayashi, Hirokazu Atsumori, Akiko Obata, Tsukasa Funane, and Takusige Katura. Tutorial on platform for optical topography analysis tools. *Neurophotonics*, 3(1):010801, 2016.

[54] Marcela Pena, Atsushi Maki, Damir Kovacic, Ghislaine Dehaene-Lambertz, Hideaki Koizumi, Furio Bouquet, and Jacques Mehler. Sounds and silence: an optical topography study of language recognition at birth. *Proceedings of the National Academy of Sciences*, 100(20):11702–11705, 2003.

[55] AL Giraud, C Kell, C Thierfelder, P Sterzer, MO Russ, C Preibisch, and A Kleinschmidt. Contributions of sensory input, auditory search and verbal comprehension to cortical activity during speech processing. *Cerebral cortex*, 14(3):247–255, 2004.

[56] Frank Mirz, Therese Ovesen, Koichi Ishizu, Peter Johannsen, Stig Madsen, Albert Gjedde, and Christian B Pedersen. Stimulus-dependent central processing of auditory stimuli: a pet study. *Scandinavian Audiology*, 28(3):161–169, 1999.

[57] Ned T Sahin, Steven Pinker, and Eric Halgren. Abstract grammatical processing of nouns and verbs in broca's area: evidence from fmri. *Cortex*, 42(4):540–562, 2006.

[58] Toshiharu Nakai, Chikako Kato, and Kayako Matsuo. An fmri study to investigate auditory attention: a model of the cocktail party phenomenon. *Magnetic Resonance in Medical Sciences*, 4(2):75–82, 2005.

[59] Felix Bermpohl, Alvaro Pascual-Leone, Amir Amedi, Lotfi B Merabet, Felipe Fregni, Nadine Gaab, David Alsop, Gottfried Schlaug, and Georg Northoff. Attentional modulation of emotional stimulus processing: an fmri study using emotional expectancy. *Human brain mapping*, 27(8):662–677, 2006.

[60] Magdalena Kachlicka, Kazuya Saito, and Adam Tierney. Successful second language learning is tied to robust domain-general auditory processing and stable neural representation of sound. *Brain and language*, 192:15–24, 2019.

[61] Michal Mazur, Rafal Rzepka, and Kenji Araki. Mixing words and emotions-new natural methods for artificial language tutors. In *The 26th Annual Conference of the Japanese Society for Artificial Intelligence (2012)*, pages 3P2IOS2b1–3P2IOS2b1. The Japanese Society for Artificial Intelligence, 2012.

[62] Elizabeth A Kensinger and Suzanne Corkin. Effect of negative emotional content on working memory and long-term memory. *Emotion*, 3(4):378, 2003.

[63] Eszter Tisljár-Szabó and Csaba Pléh. Ascribing emotions depending on pause length in native and foreign language speech. *Speech Communication*, 56:35–48, 2014.

[64] Ana P Pinheiro, Carla Barros, Marcelo Dias, and Margaret Niznikiewicz. Does emotion change auditory prediction and deviance detection? *Biological psychology*, 127:123–133, 2017.

[65] Michael Deppe, Wolfram Schwindt, Harald Kugel, Hilke Plassmann, and Peter Kenning. Nonlinear responses within the medial prefrontal cortex reveal when specific implicit information influences economic decision making. *Journal of Neuroimaging*, 15(2):171–182, 2005.

[66] Klaus R Scherer, Rainer Banse, and Harald G Wallbott. Emotion inferences from vocal expression correlate across languages and cultures. *Journal of Cross-cultural psychology*, 32(1):76–92, 2001.

[67] Kristen A Lindquist, Lisa Feldman Barrett, Eliza Bliss-Moreau, and James A Russell. Language and the perception of emotion. *Emotion*, 6(1):125, 2006.

[68] Larry Cahill and James L McGaugh. A novel demonstration of enhanced memory associated with emotional arousal. *Consciousness and cognition*, 4(4):410–421, 1995.

[69] W3C Web Accessibility Initiative (WAI). Web content accessibility guidelines (wcag) overview, 2005.

[70] M Osaka. The memo pad of brain: working memory, 2002.

[71] K Otsuka and M Miyatani. Target words and sentences for japanese version of the reading span test. *Hiroshima Psychological Research*, 7:19–33, 2007.

[72] Meredyth Daneman and Patricia A Carpenter. Individual differences in working memory and reading. *Journal of verbal learning and verbal behavior*, 19(4):450–466, 1980.

[73] Naomi P Friedman and Akira Miyake. Comparison of four scoring methods for the reading span test. *Behavior research methods*, 37(4):581–590, 2005.

[74] Maurits van den Noort, Peggy Bosch, Marco Haverkort, and Kenneth Hugdahl. A standard computerized version of the reading span test in different languages. *European Journal of Psychological Assessment*, 24(1):35–42, 2008.

[75] Toru Yoshikawa. A report on procedure in developing a malay reading span test. *Journal of the Organization for General Education Saga University*, 3:99–110, 2015.

[76] Lan Nguyen, Karen Murphy, and Glenda Andrews. Cognitive and neural plasticity in old age: A systematic review of evidence from executive functions cognitive training. *Ageing research reviews*, page 100912, 2019.

[77] Michael Petrides and Deepak N Pandya. Efferent association pathways from the rostral prefrontal cortex in the macaque monkey. *Journal of Neuroscience*, 27(43):11573–11586, 2007.

[78] Narender Ramnani and Adrian M Owen. Anterior prefrontal cortex: insights into function from anatomy and neuroimaging. *Nature reviews neuroscience*, 5(3):184, 2004.

[79] Atsuko K Yamazaki, Hitomi Shimada, and Kaoru Eto. A preliminary examination of the effect of white and blue backgrounds on web-based english listening tests. *Procedia Computer Science*, 22:529–536, 2013.

[80] Alexander C Schütz, Doris I Braun, and Karl R Gegenfurtner. Eye movements and perception: A selective review. *Journal of vision*, 11(5):9–9, 2011.

[81] Mariam Adawiah Dzulkifli and Muhammad Faiz Mustafar. The influence of colour on memory performance: A review. *The Malaysian journal of medical sciences: MJMS*, 20(2):3, 2013.

[82] Silvia Ioan, Miriam Sandulache, Sinziana Avramescu, Andrei Ilie, Alexandru Neacsu, Leon Zagrean, and Mihai Moldovan. Red is a distractor for men in competition. *Evolution and Human Behavior*, 28(4):285–293, 2007.

[83] Timo Gnambs, Markus Appel, and Kai Kaspar. The effect of the color red on encoding and retrieval of declarative knowledge. *Learning and Individual Differences*, 42:90–96, 2015.

[84] Christof Kuhbandner, Bernhard Spitzer, Stephanie Lichtenfeld, and Reinhard Pekrun. Differential binding of colors to objects in memory: Red and yellow stick better than blue and green. *Frontiers in psychology*, 6:231, 2015.

[85] Megan R Gunnar. Quality of early care and buffering of neuroendocrine stress reactions: Potential effects on the developing human brain. *Preventive medicine*, 27(2):208–211, 1998.

[86] Bart Rypma, Vivek Prabhakaran, John E Desmond, and John DE Gabrieli. Age differences in prefrontal cortical activity in working memory. *Psychology and aging*, 16(3):371, 2001.

[87] Anna Alkozei, Ryan Smith, Derek A Pisner, John R Vanuk, Sarah M Berryhill, Andrew Fridman, Bradley R Shane, Sara A Knight, and William DS Killgore. Exposure to blue light increases subsequent functional activation of the prefrontal cortex during performance of a working memory task. *Sleep*, 39(9):1671–1680, 2016.

[88] Richard H Hall and Patrick Hanna. The impact of web page text-background colour combinations on readability, retention, aesthetics and behavioural intention. *Behaviour & information technology*, 23(3):183–195, 2004.