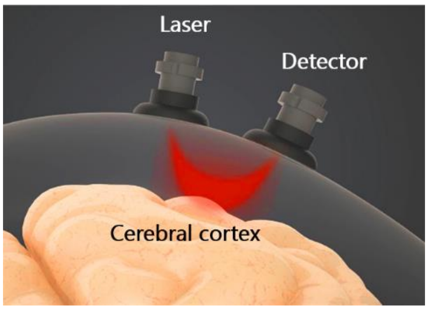
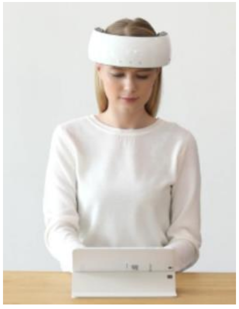
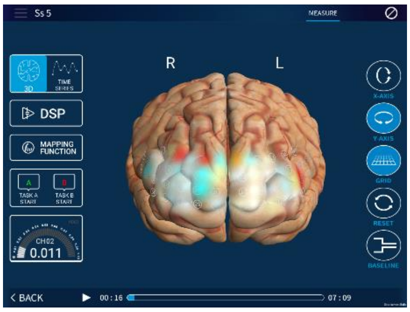
Near-Infrared Spectroscopy (NIRS)-Based Mental Stress Assessment

Introduction



NIRSIT Near-Infrared Spectroscopy (NIRS) is a noninvasive optical technique that can measure concentration changes of oxyhemoglobin (Oxy-Hb) and deoxyhemoglobin (DeoxyHb) in the cerebral vessels by means of detecting the absorption spectra of hemoglobin in the near infrared range. Systems utilizing NIRS with high portability and usability have been developing rapidly. Compared to the traditional neuroimaging devices, such as fMRI, the cost of NIRS systems are relatively low. These characteristics make NIRS system an ideal neuroimaging device to monitor people's cortical activity during daily lives, i.e., outside of the laboratory. Specifically, thanks to its portability and convenience in usage, *NIRSIT* (OBELAB Inc.,) is utilized in monitoring people's cortical activations during daily activity. This is the first study to use NIRSIT for monitoring cortical activation and mental stress assessment.



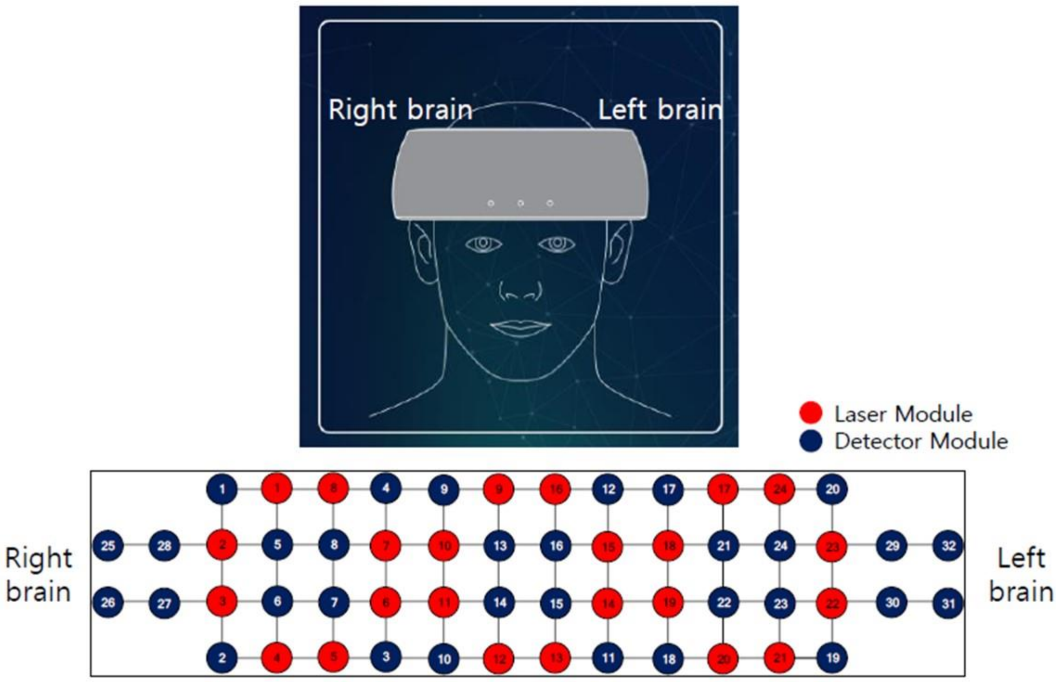


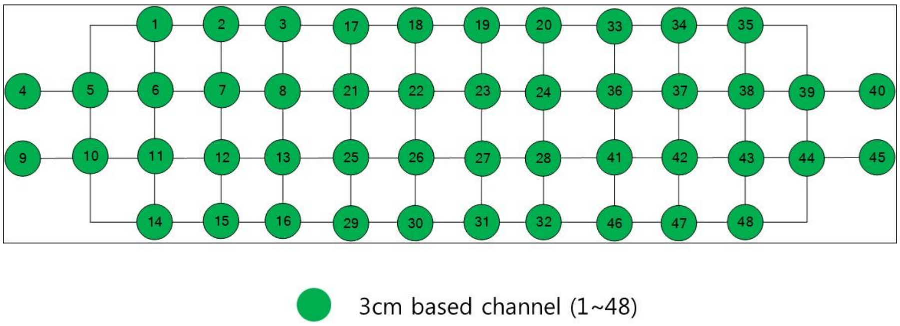
Stress Assessment One of the crucial problems people face in modern lifestyle is *mental stress*. It causes many health problems, such as cardiovascular diseases, psychiatric and psychological disorders. Conventional methods to assess mental stress involve employment of questionnaires like State-Trait Anxiety Inventory or tracking salivary cortisol level and physiological signals such as heart rate variability. However, these methods alone cannot guarantee objectivity of the assessment result. Alternatively, many researchers have found that mental arithmetic tasks under time pressure induces mental stress and the effect of stress is sensitively revealed by the activation in prefrontal cortex (PFC) region [Arnsten, 2009; Dedovi, et al., 2005]. PFC is the most evolved brain region responsible for the highest cognitive function in human brain, such as regulating thoughts, actions, and emotions. On the basis of these findings, we assumed that NIRSIT can be a convenient and novel tool for mental stress assessment by monitoring cortical activation in the PFC region during performance of mental arithmetic task.

Current Study We aimed to assess mental stress level by measuring the hemodynamic responses at the PFC region while the subject is performing mental arithmetic task. To achieve this, we developed three levels of arithmetic task difficulty as one stressor factor to induce various degrees of stress on the subject and used time pressure as an additional stressor factor. Hemodynamic responses were measured using a portable multi-channel NIRS system, NIRSIT, while the subject performed tasks with varying levels of arithmetic task difficulty, i.e., mental stress.

Methods

Instrumentation and Optode Placement The source and detector array of NIRSIT is shown in the figure below. The array is composed of 24 sources and 32 detectors for multi-distance detection. The number of channels covered by NIRSIT is 204, consisting of 68 channels based on 3 cm, 52 channels based on 1.5 cm, 36 channels based on 2.12 cm, and 48 channels based on 3.35cm distance. All 204 channels are detected simultaneously with a temporal resolution of 122.88 msec. NIRSIT uses custom-made dual-wavelength vertical-cavity surface-emitting laser (VCSEL) using 780nm and 850nm. The light traveling through the brain channel is detected by Si-PD followed by trans-impedance amplifier (TIA). The multi-channel transmitters and receivers are implemented in the ASIC and the whole system is controlled by micro-controller unit.



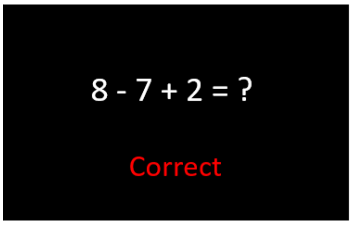


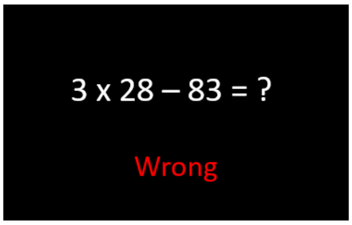
Experiment Design The experiment was developed based on the Montreal Imaging Stress Task (MIST) [Dedovic, et al., 2005]. In this study, the arithmetic task was defined at three levels of difficulty, where each level corresponded to one level of mental stress. Each level of the arithmetic task was designed as follows:

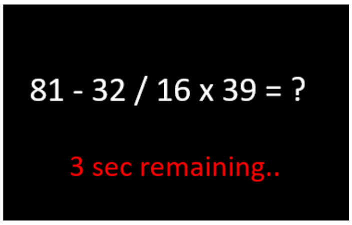
• Level 1: two or three 1-digit integers (0-9) with + and/or -. No repeated operations with random order or operations (example: 3 + 5, 8 - 7 + 2).

• Level 2: three integers, one or two integers are double digits (0-99). Operands +, -, or * were used. No repeated operations with random selection and random order of operations (example: 5 + 50 - 51, 3 * 28 - 83).

• Level 3: four integers, one to four integers are double digits (0-99). Operands +, -, *, or / were used. No repeated operations with random selection and random order of operations (example: 25 + 1 * 3 - 26, 81 - 32 / 16 * 39)





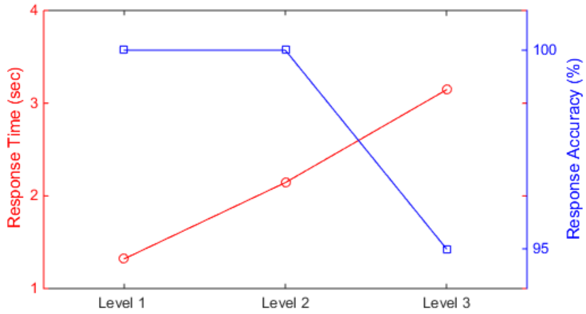


In addition to the varying difficulty in mental arithmetic task, individual time restriction was implemented to induce mental stress on the subjects. Subjects were first trained at each level of task difficulty, at which time the average durations of time each individual needed in answering the questions were recorded. To avoid frequent trial misses, restriction placed on individual's duration of time was set by taking into account the average duration of time and the margin with two standard deviations. Moreover, feedback of answering the questions ("correct" or "wrong") and the countdown of remaining time ("# seconds remaining") were displayed on the computer monitor to further induce stress on the experiment subjects. Stimuli presentation in MATLAB (R2014b; The MathWorks, Inc., Natick, MA, USA) was programmed with Psychophysics Toolbox extensions [Kleiner et al. 2007].

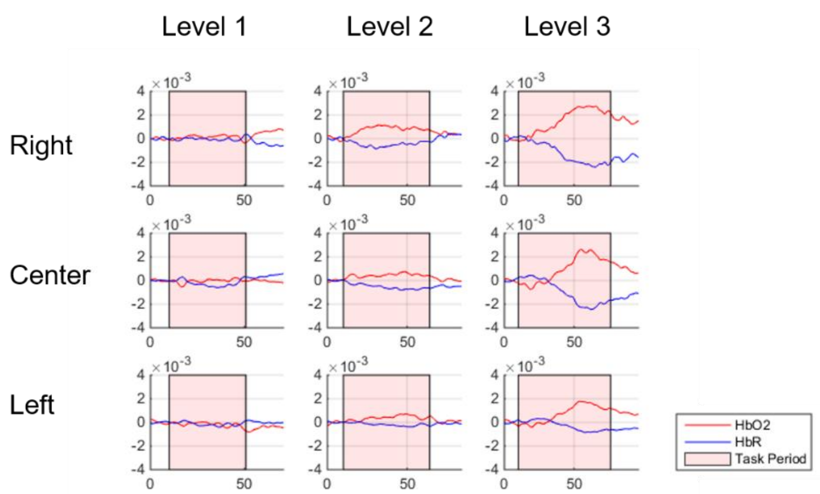
Data Analysis MATLAB was used for data analysis. The detected light intensity is filtered by low pass filter with a 0.05Hz cutoff frequency. After that, channel rejection process was performed to identify and reject those channels that are prone to noise by evaluating the SNR of each channel. The modified Beer-Lambert law (MBLL) was applied to calculate hemodynamic responses from light intensity changes [Delpy et al., 1988]. To note, among 204 channels, only 3cm channels were used for further analysis, as it is generally well accepted that 3cm channels are known to capture the hemodynamic response in a human brain with optimum outcome.

Results

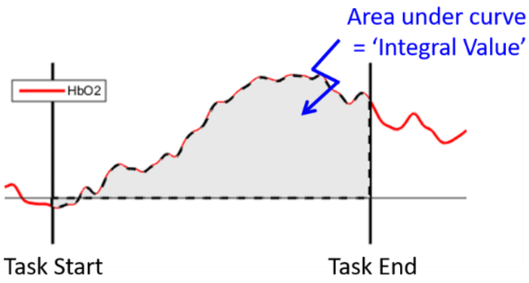
Behavior Responses During the performance of mental arithmetic task by the subjects, individual response time and accuracy were recorded for each task level. Here is a plot with y-axis showing response time (sec) on the left side and response accuracy (%) on the right side. As clearly shown in the figure, varying difficulty of the task affected subjects' behavior responses, i.e., response time and accuracy.



Temporal Hemodynamic Responses As can be seen in the figure below, the time course of hemodynamic responses demonstrated significant increase in HbO2 and decrease in HbR during performance of mental arithmetic task compared to the baseline. The amount of concentration changes in HbO2 and HbR became larger as a level of the task difficulty became higher.



Stress Level Indicator As a quantitative measure of mental stress, the 'integral value' that has been used for a mental disorder diagnosis was used [Takizawa et al., 2014]. The integral value was calculated by the size or area under the curve of the hemodynamic response during the task period, representing the amount of the cortical activation captured by the concentration of the oxygenated hemoglobin.

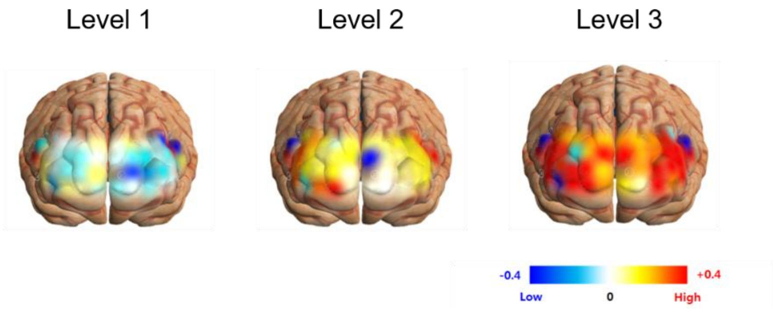


Mean integral values of 16 channels for each PFC region (right, center, and left) are reported in the following table.

	Level 1	Level 2	Level 3
Right	0.02 (0.17)	0.20 (0.23)	0.48 (0.71)
Center	-0.03 (0.12)	0.09 (0.26)	0.34 (0.20)
Left	-0.04 (0.28)	0.23 (0.18)	0.48 (0.31)

*Numbers in parenthesis indicate standard deviations.

To observe the spatial distribution of mental stress effect on the hemodynamic responses, the topographic map was generated on the basis of the integral value as defined above. Values between channels were interpolated. As clearly seen in the picture, the effect of mental stress during performance of the mental arithmetic tasks became larger as a level of task difficulty became higher.



Reference

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