NIR Spectroscopy Measurements of Cognitive Load Elicited by GKT and Target Categorization

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ABSTRACT

Near infrared (NIR) is a portable, safe, affordable, non-invasive and negligibly intrusive functional optical imaging modality, which enables the measurement of the metabolic changes associated with cognitive activity. In this paper, we present the experimental procedures and data analysis of the functional near infrared (fNIR) measurements acquired from the forehead during cognitive tasks. The data is collected from subjects engaged in two standardized tasks, namely, the 'target categorization' and the 'guilty knowledge test' (GKT). In the case of target categorization, the aim is to study the changes in the blood oxygenation and volume level while the participants are experiencing decrements in vigilance, increased lapses of attention, cognitive slowing. We measured 25 minutes-long blood oxygenation and volume level changes during target responses in 11 participants performing Target Categorization. Data analysis results revealed that the level of oxygenation changes in missed targets is higher than the level in captured targets. The blood oxygenation and volume level changes during deceptive and truthful responses were measured in 16 participants performing the GKT and analyzed using statistical data analysis. The results of our data analysis showed that the level of oxygenation changes during 'lie' task is higher than the level during 'truth' task.

1. INTRODUCTION

Human brain imaging techniques, such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) have dramatically increased our knowledge about the neural circuits that subserve cognitive and emotional processes [1,2]. However, these techniques are expensive, physically constraining, confine the participants to restricted positions, and may expose them to potentially harmful materials (PET) or loud noises (fMRI). These characteristics make them unsuitable for many uses, including the monitoring of ongoing cognitive activity under routine working conditions.

Near infrared spectroscopy (NIRS) enables the measurement of changes in the concentration of deoxygenated hemoglobin (deoxy-Hb) and oxygenated hemoglobin (oxy-Hb) noninvasively during functional brain activation in human [3-5]. The system is portable, relatively inexpensive, non-invasive, negligibly intrusive and can be used repeatedly with the same participants. This makes NIRS suitable for the study of cognition related hemodynamic changes under many working conditions (e.g., computer operation) and in the field.

In principle, brain activation causes an increase in local cerebral blood flow (CBF) that occurs within several seconds. This increase in CBF and oxygen delivery exceeds the increase in local oxygen consumption. Hence, cerebral blood oxygenation rises locally [5]. Oxygenated and deoxygenated hemoglobin have characteristic optical properties in the visible and near-infrared light range. Therefore, based on functional optical measurements, concentration changes of these molecules can be measured during

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functional brain activation [3,5]. Biological tissues are relatively transparent to light in the near infrared range between 700-900 nm. This 'optical window' allows assessment of brain activity non-invasively. Using this technique, several types of brain functions have been assessed, including motor and visual activation, auditory stimulation and performance of cognitive tasks [5].

Complex tasks (e.g. computer operation, navigating an Unmanned Air Vehicle,…) are comprised of a collection of discreet cognitive tasks and abilities, such as category discrimination, target detection, working memory, etc. To assess and provide neurophysiological feedback on a more complex task (e.g. the effects of fatigue on operator performance), we must first understand how each of these discreet cognitive tasks contributes to overall performance, and how they affect neurophysiological signals.

In this paper, the following set of studies is carried out with functional near infrared (fNIR) to examine prefrontal cortex activation while participants are engaged in two standardized cognitive tasks. Then, hemodynamic measures by fNIR and the results of the data analysis will be presented.

2. METHODS

2.1 Subjects

The subjects for this study were male adults aged 18 to 35. 16 neurologically normal volunteers participated in GKT and 11 volunteers participated in Target Categorization

2.2 Tasks

i. Guilty Knowledge Task

The paradigm uses a socially acceptable form of deception (the game of poker) to determine if fNIR can identify an individual's attempt to conceal information.

In our experiments, subjects are asked to select one out of 3 envelopes containing a playing card (e.g., the 5 of clubs). They are told that if they can deceive the fNIR system, they are allowed to make $10 in addition to their compensation as a subject. Subjects are then shown four categories of cards on the screen:

1. Deception card (5 of clubs)
2. Truth card (2 of hearts)
3. Non- target cards (random cards)
4. Control cards (4 of hearts, 2 of clubs, 3 of diamonds, 6 of spades)

For the 'deception', 'nontarget', and 'truth' cards, subjects are asked the question: "Do you have this card?" For the 'control' cards, subjects are asked "Is this a [4 of hearts]?." Cards are presented for 3 seconds, with 12 seconds in between each card.

ii. Target Categorization

This is a simple discrimination task, or "oddball" paradigm, in which subjects are presented with two stimuli or classes of stimuli in a Bernoulli sequence in the center of the screen. The probability of one stimulus is less than the other (e.g. 20% of trials for the "target" or "oddball" stimulus, versus 80% of trials for the "typical" or "context" stimulus); the participant's task is to count or press a button when they see the less frequent of the two events. Stimulus categories are varied, beginning with the letters "XXXXX" versus the letter "OOOOO". 1,024 stimuli are presented at 1500 ms intervals (total time: 25 minutes); one target "XXXXX" is presented on 64 trials, with a minimum of 12 context stimuli ("OOOOO") in between to allow for the hemodynamic response.

2.3 Experimental Setup

Figure 1(a) below shows a block diagram of the fNIR instrument built for monitoring brain activity. Figure 1(b) shows the source-detector locations on the fNIR probe. The source-detector separator is set at three cm. for this design. There are two probes to cover each hemisphere on the brain's frontal lobe.

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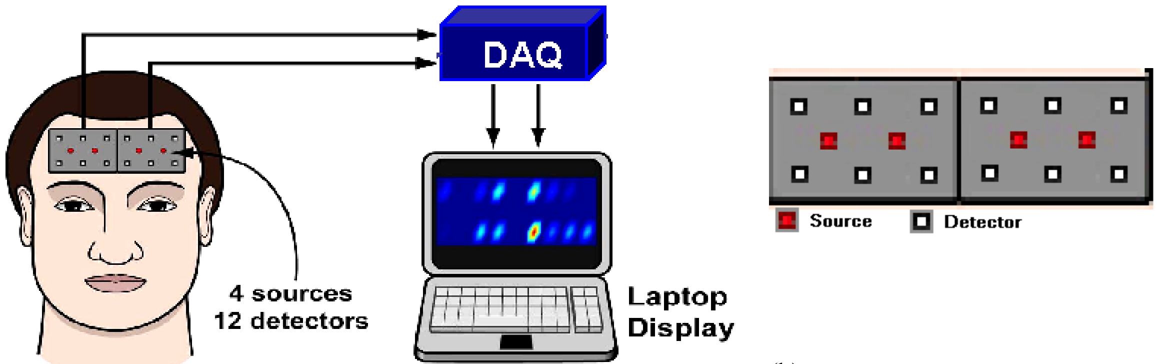

(b)

(a)

Figure 1(a) A Block diagram of the fNIR system, showing the data acquisition board (DAQ) that hosts the electronic systems to turn the light sources on and collect the reflected light from the two sets of probes. (b) A probe with four light sources and twelve detectors (photodiodes).

3. DATA ANALYSIS

3.1 Preprocessing

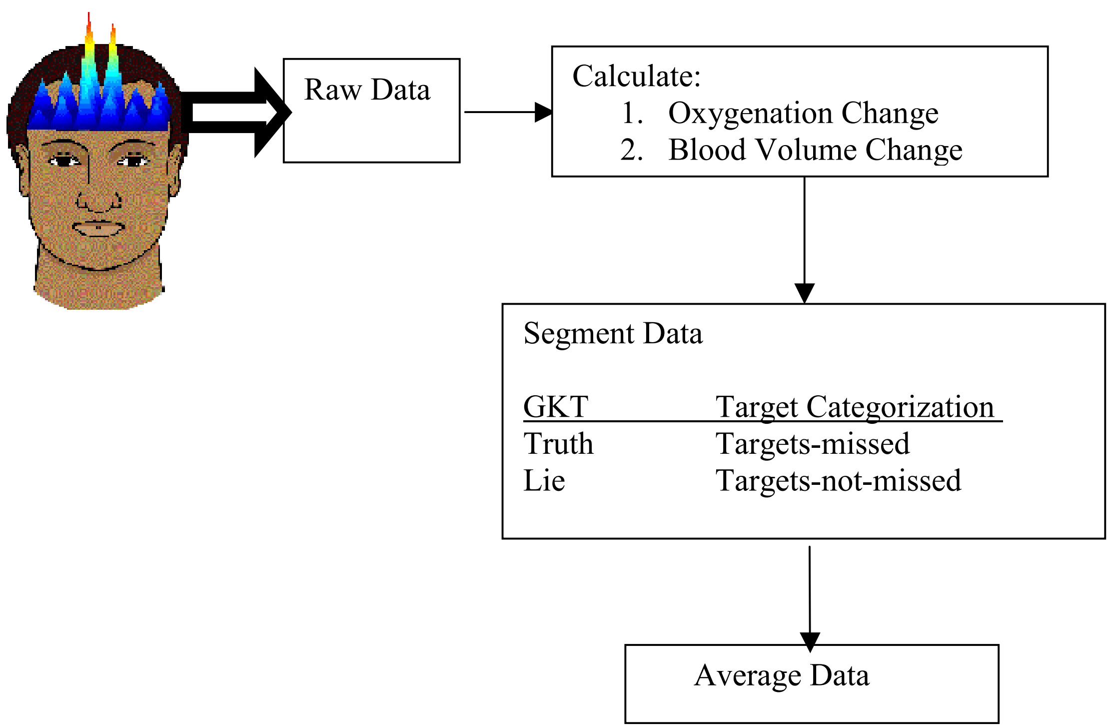

Figure 2. Block Diagram of the Preprocessing

From the raw data, we calculate changes in oxygenation and blood volume using Modified Beer Lambert Law [9], then segment data into the regions (Truth and Lie for GKT; Targets-missed and targets-not-missed for Target Categorization), we then average the data for each segment as the output of this process is shown in Figure 3 and 4.

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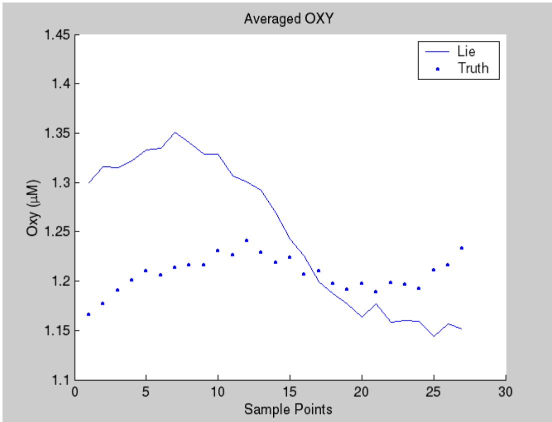

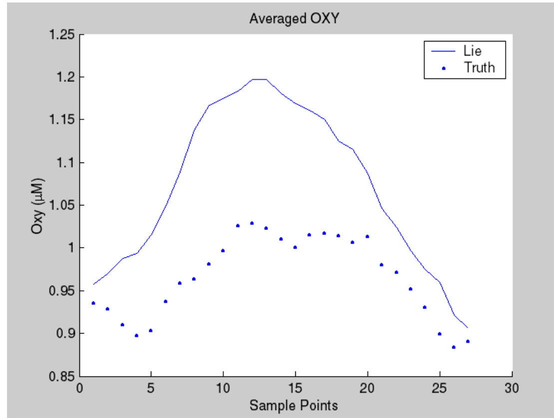

a) Sample Subject 1 b) Sample Subject 2

Figure 3. Averaged Oxygenation Response of the subject to Truth and Lie

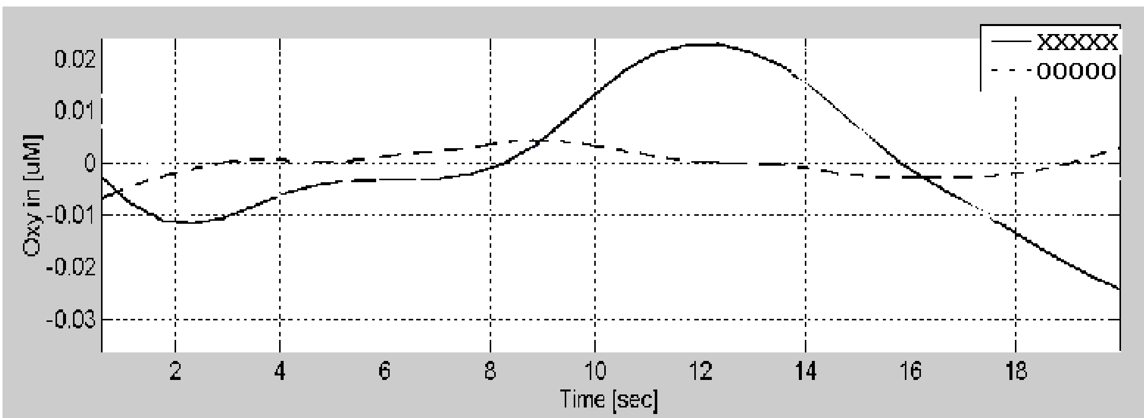

Figure 4. Averaged Oxygenation Responses of the subject to XXXXXs and OOOOOs

3.2 Statistical Data Analysis

We implemented the t-test as the simplest and most widely used analysis technique in order to decide between the null hypothesis (H_0) of no brain activation difference observed among the various tasks, i.e., XXXXX and OOOOO, and the alternative hypothesis (H_1) that the different brain activation is present. Each t-test study was calculated by constructing two groups of N samples, yielding a total of 2N samples. One group of samples represented the averaged response to *Truth* and the other group of samples represented the *Lie*. For target categorization paradigm, Truth and Lie were replaced by *targets missed by subject* and *targets not missed*, respectively.

4. RESULTS

Three participants from GKT and four participants from Target Categorization test were excluded because of the hardware-based inconveniences and motion artifacts. The final number of subjects is 13 for GKT and 7 for the Target Categorization.

4.1 . Experiment I: Guilty Knowledge Test

The test of our hypothesis yielded the significant differences between truth and lie in all subjects. In the "Lie versus Truth" t-test results (Table 1), the probability, P, was calculated at the significance level of 0.05. The numbers presented on the table are the results of calculation, (1-P) and reveal that the higher (1-P) the more significant the difference between means. In 16 channels, only channel number 3 reflected the significant difference lower than the desired significance level, 95% (1 – alpha).

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Channel 1 96.96 %	Channel 3 88.14 %	Channel 5 100 %	Channel 7 100 %	Channel 9 99.97 %	Channel 11 100 %	Channel 13 100 %	Channel 15 100 %
Channel 2 100 %	Channel 4 100 %	Channel 6 100 %	Channel 8 100 %	Channel 10 100 %	Channel 12 100 %	Channel 14 21.6	Channel 16 100 %

Table 1. t-test results for *GKT* Significance level; alpha = 0.05, the numbers shown on the table are the results of calculation, (1-P), where P is the probability calculated at the given alpha.

Channel 1 100 %	Channel 3 100 %	Channel 5 100 %	Channel 7 100 %	Channel 9 100 %	Channel 11 100 %	Channel 13 100 %	Channel 15 100 %
Channel 2 100 %	Channel 4 100 %	Channel 6 100 %	Channel 8 100 %	Channel 10 100 %	Channel 12 100 %	Channel 14 21.6	Channel 16 100 %

Table 2. t-test results for *Target Categorization*: Significance level; alpha = 0.05, the numbers shown on the table are the results of calculation, (1-P), where P is the probability calculated at the given alpha.

In addition, the grouped average responses among the subjects showed the following trend: For 8 out of 13 subjects, the level of oxygenation changes during Lie task was higher than the level during Truth task as depicted in Figure 3.

4.2 . Experiment I: Target Categorization

Several studies demonstrate that the infrequent targets ('XXXXX') not only elicit P300, also activate some of the same neural circuitry active in working memory tasks in both humans and monkeys [6]. Hence, it is one of our hypotheses that the fNIR studies should present the equivalent response to the infrequent targets. As shown in Figure 4, the response to 'XXXXX' (infrequent targets), is comparatively higher than the response to 'OOOOO's.

Another test of our hypothesis yielded the significant differences between *targets missed by subject* and *targets not missed.* In the "targets-missed versus targets-not-missed" t-test results (Table 2), the probability, P, was calculated at the significance level of 0.05. The numbers presented on the table are the results of calculation, (1-P) and reveal that the higher (1-P) the more significant the difference between means. In 16 channels, only channel number 14 reflected the significant difference lower than the desired significance level, 95% (1 – alpha). In addition, the grouped average responses among the subjects showed the following trend: For 5 out of 7 subjects, the level of oxygenation changes in targets-missed was higher than the level in targets-not-missed as shown in Figure 5.

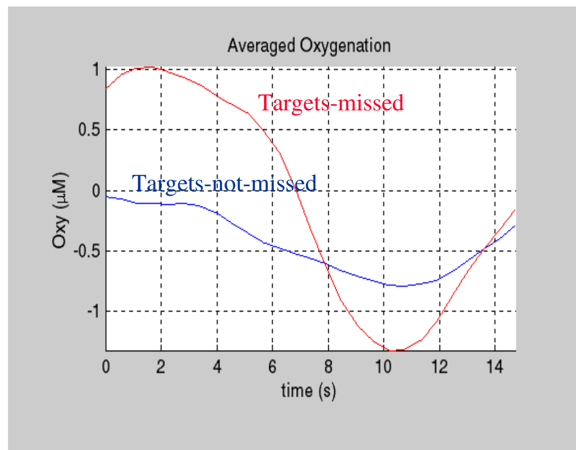

Figure 5. Averaged Oxygenation Response of the subject to targets-missed and targets-not-missed

5. CONCLUSION

This paper demonstrates that NIR based functional optical brain imaging sensor provides information about the metabolic state associated with cognitive state. The findings using GKT model of deception and target categorization task example of working memory validate the fNIR as a means to monitor prefrontal cortex activity during select tasks relevant to cognition. Further improvements in hardware design, increasing the number of subjects and applying more advanced signal processing techniques will definitely decrease the error margin in trend analysis and make fNIR a powerful real-time detection device to monitor the cognitive state of the user.

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