

Human-Computer Interaction and Brain Measurement Using Functional Near-Infrared Spectroscopy

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ABSTRACT

Functional near-infrared spectroscopy (fNIRS) is an emerging non-invasive, lightweight imaging tool which can measure blood oxygenation levels in the brain. We present an experiment showing how it could be used in human-computer interaction. We use machine learning techniques to analyze fNIRS data to classify different levels of mental workload. Using our fNIRS measurements and machine learning algorithms, we were able to distinguish different levels of user workload and interaction styles in a computer task with average accuracy as high as 83% across subjects. Our results show the feasibility of using fNIRS in HCI research.

ACM Classification: H5.2 [Information interfaces and presentation]: User Interfaces. - Graphical user interfaces.

General terms: Design, Human Factors, Experimentation

Keywords: brain computer interfaces (BCI), workload, fNIRS, interaction styles

INTRODUCTION

Acquiring measurements about the mental state of a computer user would be valuable in Human-Computer Interaction (HCI), both for evaluation of interfaces and for real time input to computer systems. Although we can accurately measure task completion time and accuracy, measuring factors such as mental workload, frustration and distraction are typically limited to qualitatively observing users or administering subjective surveys to users. These surveys are often taken after the completion of a task, potentially missing valuable insight into the user's changing experiences throughout the task. New evaluation techniques that monitor user experiences while working with computers are increasingly necessary. To address these evaluation issues, much current research focuses on developing objective techniques to measure in real time user states such as workload, emotion, and fatigue. Although this ongoing research has advanced user

experience measurements in the HCI field, finding accurate, non-invasive tools to measure computer users' states in real working conditions remains a challenge.

We investigate functional near-infrared spectroscopy (fNIRS) [1], a relatively new technology for brain activity measurement, which we combine with the use of machine learning to analyze the resulting data. The emerging fNIRS tool is safe, portable, non-invasive, and can be implemented wirelessly, allowing for use in real world environments, making naturalistic HCI possible.

In addition to aiding in the evaluation of interfaces, fNIRS output offers potential as an additional parallel, lightweight input channel for users. This additional information from the brain could be used to improve the efficiency, or intuitiveness of the user's interaction with the machine and to provide new access methods for disabled users.

This poster presents our first experiment with the fNIRS tool and demonstrates its feasibility and potential for HCI settings. We distinguish several discrete levels of workload that users experienced while completing different tasks.

Functional Near-Infrared Spectroscopy (fNIRS)

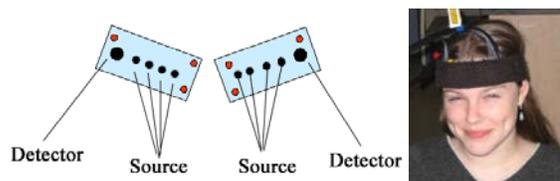


Figure 1. : Left: A schematic diagram of two detectors and their set of sources. Right: The fNIRS device placed on each side of the forehead held in place by the headband.

Functional near-infrared spectroscopy measures hemoglobin concentration and tissue oxygenation in the brain. It uses light sources placed on the scalp to send near-infrared light into the head. Biological tissues are relatively transparent at these wave lengths, so the light attenuation through tissues is sufficiently low to allow for tissue imaging at depths up to 2-3 centimeters. Deoxygenated and oxygenated hemoglobin are the main absorbers of near-infrared light in tissues, and they provide relevant markers of hemodynamic and metabolic changes associated with

neural activity in the brain. Therefore, fNIRS researchers can estimate hemodynamic changes by using light detectors to monitor reflected light that has probed the brain cortex [2]. Figure 1 displays an example of the arrangement of light detectors and sources in an fNIRS device.

WORKLOAD AND INTERACTION STYLE EXPERIMENT

Our goal for this study was to see whether our approach could measure frontal lobe activity such as workload and to apply the preprocessing and machine learning techniques to classify levels of workload.

Four subjects completed thirty tasks where they viewed the top and all sides of a rotating three dimensional (3D) shape comprised of eight small cubes. Figure 2 illustrates an example of a rotating shape. In the experiment, cubes could be colored with two, three, or four colors, which we hypothesized lead to different workload levels. During each task, subjects counted the number of squares of each color displayed on the rotating shape in front of them. A blank screen represented the baseline state (no colors).



Figure 2. A cube made up of eight smaller cubes.

Task A: Graphical Blocks

The main goal of this experiment was to decide whether fNIRS data is sufficient for determining the workload level of users as they perform tasks. To accomplish this, a graphical interface displayed the rotating shapes.

Task B: Graphical versus Physical Blocks

We also wanted to determine whether there is a difference in mental workload when a user completes a spatial reasoning task on a graphical display versus completing the task using a physical object, such as a tangible user interface. Prior research on the comparisons between tangible interfaces and graphical user interfaces was the catalyst for inclusion of this condition [3]. Therefore, we included a physical cube of workload three, with the same rotation time and size as the graphical cube of that level.

At the completion of each task, the subject was prompted their answer. Then, the subject was instructed to rest for thirty seconds, allowing the brain to return to a baseline state. After completing the tasks, the subject was presented with an additional example of each workload level and asked to fill out a NASA-Task Load Index, administered to compare our results with an established measure of workload. The results validate our workload levels: increased number of colors leads to higher workload level.

Data Analysis and Results

We preprocessed the data by normalizing it, applying a detrending algorithm and using a sliding window paradigm to generate average and slope features. Using a blocked cross-validation, we classified the data with a multilayer perceptron classifier. We tested distinguishing all five workload levels from each other, as well as comparisons of two, three, and four workload conditions of the graphical

workload level, and we compared graphical and physical workload level three.

Analysis of Graphical versus Physical Blocks

The average accuracy was 83%, with a range from 73% to 91%. These positive classification results are useful from a HCI perspective—there were distinguishable differences between displaying a cube in a graphical vs. physical user interface. Although we can accurately distinguish between the cognitive activities experienced in these two conditions, we cannot say for sure whether the difference is attributable to the workload of the interface, the workload of the task, or other variables affecting brain activity. However, these results encourage further exploration into cognitive workload associated with different interaction styles.

Analysis of Graphical Blocks

When we consider the results comparing workload levels 0, 2, and 4, classification accuracies range from 41.15% to 69.7% depending on the subject. Considering that a random classifier would have 33.3% accuracy, the results are promising. It seems that we can predict, with relatively high confidence, whether the subject was experiencing no workload (level zero), low workload (level two), or high workload (level 4). The NASA-TLX results supported our findings: subjects reported task difficulty increasing as number of colors increased on the cube.

CONCLUSION

Our goal was to test the ability of the fNIRS device to detect levels of workload in HCI, to develop classification techniques to interpret its data, and to demonstrate the use of fNIRS in HCI. Our experiment showed several workload comparisons with promising levels of classification accuracy. One of our long term goals is to use this technology as a real time input to a user interface in a realistic setting. We observe that our equipment places no unreasonable restrictions on a subject using an interactive system, and it can collect and transmit data in real time. This proves promising for the HCI community.

ACKNOWLEDGMENTS

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