A Virtual Reality Neurofeedback Plugin for fNIRS

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Introduction

Neurofeedback is a therapeutic method in which participants can train their brain to modulate their own brain activity, enabling long-term changes in brain activity.[1] Participants real time brain activity is displayed to the participant as a form of stimuli, facilitating a bidirectional control of the signal. When compared to other neuroimaging techniques, such as functional magnetic resonance imaging (fMRI) and electroencephalography (EEG), fNIRS has a spatial and temporal resolution between fMRI and EEG2.[2] Its spatial resolution is higher than EEG, and its temporal resolution is higher than fMRI.[2] In addition, fNIRS' depth is limited to neocortical brain regions.[3] However, fNIRS' is quiet, portable, and cheaper than fMRI while allowing more head movement than EEG and fMRI enabling fNIRS' use in more realistic, natural environments (e.g. movement and interaction with other people) with more diverse populations (e.g. infants).

Problem statement

While multiple neurofeedback software for fNIRS exist, many are limited to a thermometer, rising objects, or smiling figures. Moreover, not all the current software allows for multiple ways to process the signals, commonly restricted to the amplitude or derivative of the signal.

- We intend to create a high quality virtual reality (VR) neurofeedback environment that allows for fNIRS data to be output in multiple ways. The higher quality VR environment increases the participant's immersion, leading to better neurofeedback performance.[4]
- The fNIRS signals will be able to be output as either the amplitude, derivative, correlation, or anti-correlation. In addition, the signal will be scalable in real time if needed.

Methods/approach

First, fNIRS is used to collect the signal from a participant using a source-detector optode system to shine near infrared light into the scalp, measuring the changes in light absorption of oxygenated (HbO) and deoxygenated hemoglobin (HbR).

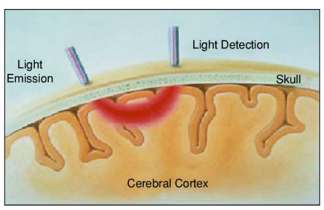

Fig. 1. fNIRS collecting optical density data

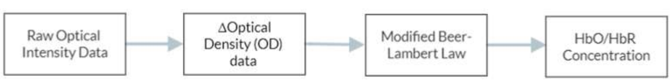

Fig. 2. fNIRS processing pipeline

These calculations are performed in Turbo-Satori, a real-time fNIRS analysis software, which are then sent to Matlab through a localhost connection. In Matlab, we modify the signal's presentation (e.g. derivative vs. amplitude). Through a TCP connection, Matlab is connected to a Unity environment in which the incoming signal is used to affect the environment.

-1.5189e-04	-0.0018	1.5916e-04	1.5916e-04
-2.6714e-04	-0.0020	1.8024e-04	1.8024e-04
-3.8112e-04	-0.0022	1.9806e-04	1.9806e-04
-5.8856e-04	-0.0027	2.0809e-04	2.0809e-04
-6.8774e-04	-0.0029	2.0571e-04	2.0571e-04
-7.6906e-04	-0.0030	2.0021e-04	2.0021e-04
-8.4812e-04	-0.0032	1.8937e-04	1.8937e-04
-9.1033e-04	-0.0033	1.6928e-04	1.6928e-04
-9.4417e-04	-0.0034	1.3754e-04	1.3754e-04
-9.6069e-04	-0.0035	1.0215e-04	1.0215e-04
-9.2976e-04	-0.0034	5.0855e-05	5.0855e-05

Fig. 3. TurboSatori signals processed in Matlab

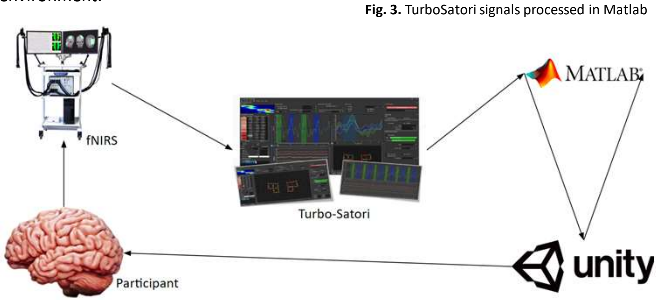

Fig. 4. Our high-level neurofeedback pipeline

Results

Our Unity environment is a forest clearing with a white tree in the center. The white tree is surrounded by tall, green grass with a field of red flowers surrounding the grass.

In addition, the scaling of the incoming signal, the minimum size, and the maximum size of the tree can be changed in real-time within the Unity environment,

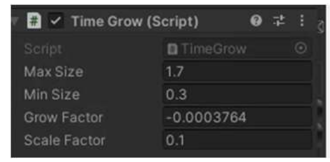

Fig. 5. Modifiable parameters in Unity

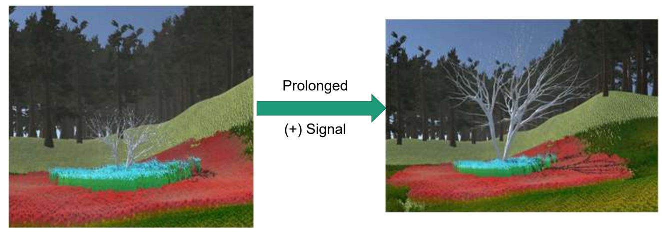

Fig. 6. Our Unity environment

The amplitude is calculated based on the distance the HbO/HbR concentration is from the participant's baseline.

The derivative is calculated based on the relationship between the amplitude of 5 signals sampled at consecutive time points.

The correlation and anti-correlation are calculated by comparing two arrays of the amplitude of 50 signals sampled at consecutive points. The two arrays represent the selected regions of interest, upon which either the correlation or anti-correlation will be calculated.

Channels can be selected within Turbo-Satori, causing the signal to change in real-time to reflect the change in channels.

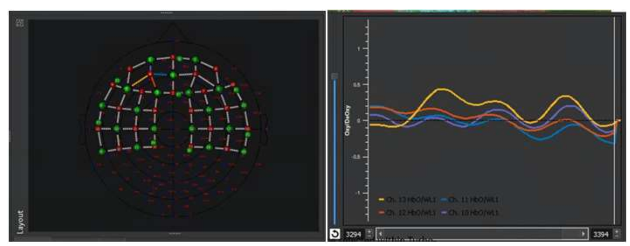

Fig. 7. Turbo-Satori with 4 channels selected overlaying the dorsolateral prefrontal cortex

Conclusions

Using Unity as our environment and Turbo-Satori as our real-time connection and pre-processing of the data stream, we have created a flexible, immersive neurofeedback environment for use with fNIRS. Because the data is completely processed before it is sent to Unity, the Unity environment can be easily modified to anything that can move based off a numerical signal (e.g. instead of the tree, a face changing emotions, a flame growing or going out, etc.). Therefore, we intend for our plugin to be used in future fNIRS neurofeedback experiments. Future directions could involve implementing a classifier to determine when a participant is in a certain "brain state" or increasing the immersion of the environment with more detailed textures and audio.

References

[1] Kohl, Simon H., et al. "The potential of functional near-infrared spectroscopy-based neurofeedback—a systematic review and recommendations for best practice." *Frontiers in neuroscience* (2020): 594.

[2] Cui, Xu, et al. "A quantitative comparison of NIRS and fMRI across multiple cognitive tasks." *Neuroimage* 54.4 (2011): 2808-2821.

[3] Pinti, Paola, et al. "The present and future use of functional near-infrared spectroscopy (fNIRS) for cognitive neuroscience." *Annals of the New York Academy of Sciences* 1464.1 (2020): 5-29.

[4] Accoto, Floriana, et al. "The Effect of Neurofeedback Training in CAVE-VR for Enhancing Working Memory." *Technology-Augmented Perception and Cognition*. Springer, Cham, 2021. 11-45.

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