fNIRS and fMRI signals are concordant during a bipedal motor task

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Introduction

fNIRS activity has previously been shown to be highly correlated (r = 0.77 – 0.94) for homologous regions with fMRI BOLD signal recordings in studies which measured concurrent fNIRS and fMRI functional activity using classic psychological and simple finger tapping paradigms

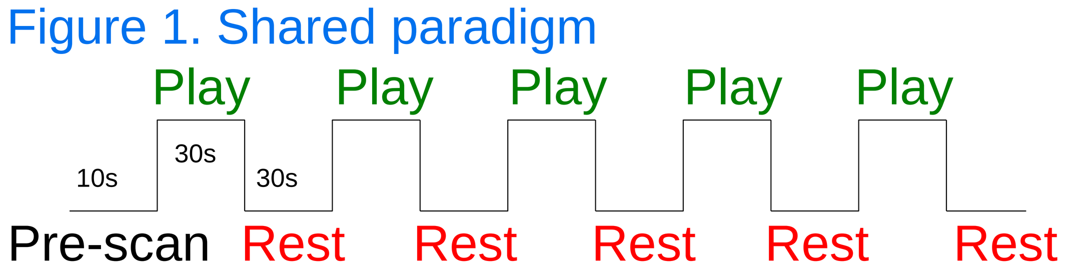
- Cui, X., et al. (2011). "A quantitative comparison of NIRS and fMRI across multiple cognitive tasks." NeuroImage **54**(4): 2808-2821.
- Heinzel, S., et al. (2013). "Variability of (functional) hemodynamics as measured with simultaneous fNIRS and fMRI during intertemporal choice." NeuroImage **71**: 125-134.
- Sato, H., et al. (2013). "A NIRS–fMRI investigation of prefrontal cortex activity during a working memory task." NeuroImage **83**: 158-173.

Here, we test a method of combined fMRI and fNIRS for determining neural mechanisms engaged during a naturalistic dance video game task. The aim of the study was to compare activity in an integration center of the brain (the superior and middle temporal gyrus) between a group of individuals imaged using fMRI to another group of subjects using a naturalistic version of the task imaged using fNIRS. Our hypothesis was that functional activity in this area as recorded using fNIRS would be significantly correlated with functional activity recorded using fMRI in a similar but limited dance game protocol.

Materials and Methods

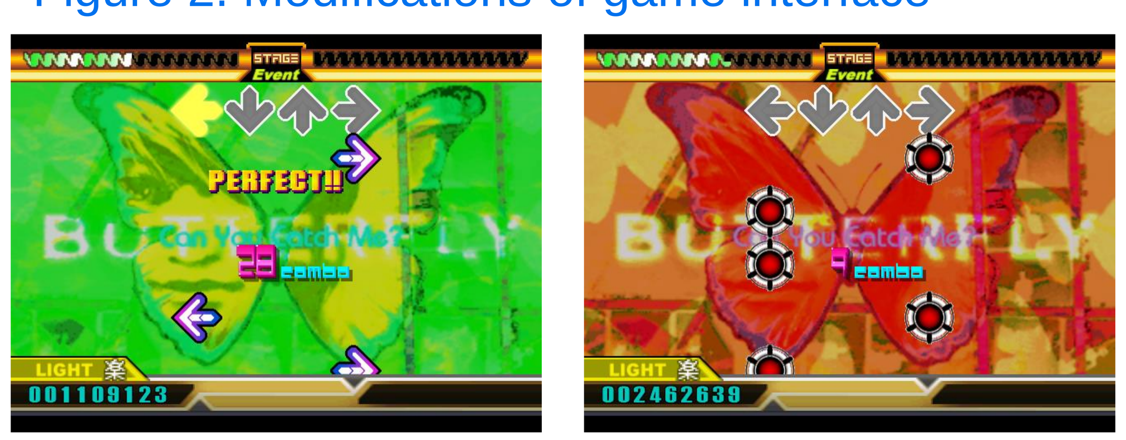
We modified the open-source clone of the game Dance Dance revolution to be played using a block design consisting of alternating play and rest epochs. The time series of the design is seen below:

Figure 1. Shared paradigm



The block design used for both fNRIS and fMRI scanning consisted of a total of 5 minutes of 30 second play and rest epochs. The pre-scan was 10s in length, followed by alternating 30s play and rest blocks.

Figure 2. Modifications of game interface



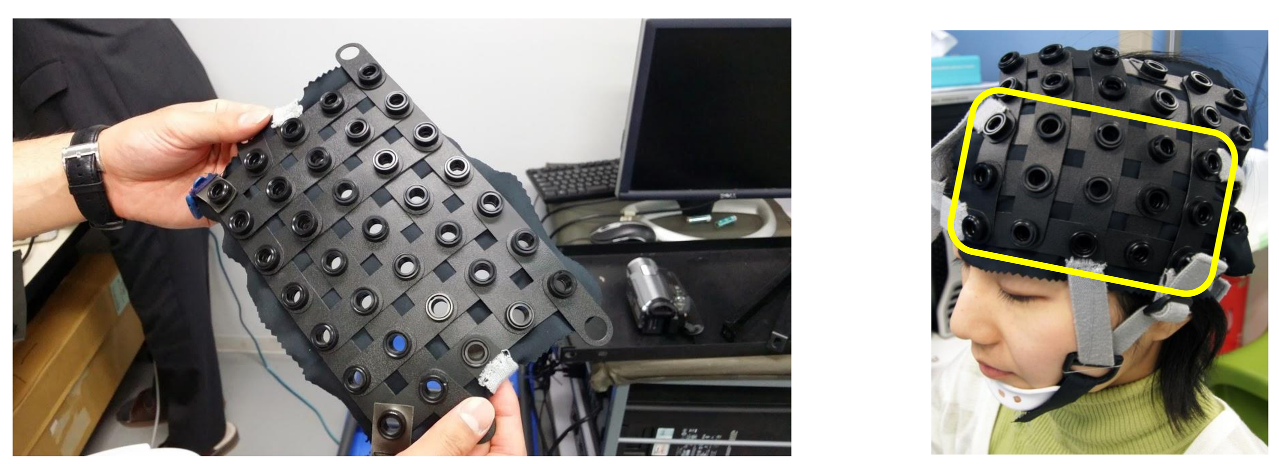
The playable graphic interface of Stepmania was modified to cue the players of the play and rest epochs by changing the color of the background graphics and the interactive arrow stimuli. During play epochs, the background changed to green and during rest epochs the background was red. Arrow cues present in the play epochs were changed to “bombs” in the rest epochs to stimulate the visual field in the same way as the play epoch. Players were told the bomb looked similar to a stop sign and the red color also meant stop as in a traffic signal. In fMRI data collection, we removed up and down arrows (and corresponding responses) to reduce motion artifact due to leg motions.

Figure 3. Data collection (fMRI)

The experimental setup for fMRI is shown above. The figure on the left shows how a subject lies on the collection platform with knees bent supported using a foam insert. The figure on the right shows the modified response pad subjects played the game with. During collection, subjects lay in the MRI scanner while observing the projected interactive environment using a mirror mounted to the head coil above the subject. Subjects perform two rounds of the paradigm outlined in Figure 1 for a total of 10 minutes of gameplay.

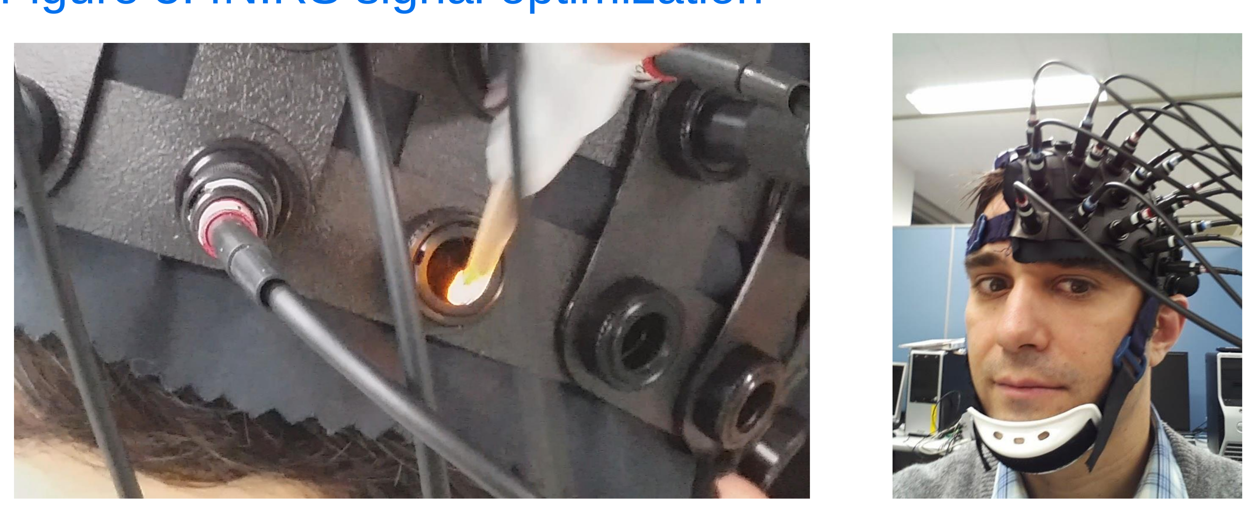
- The MRI scanner used in this study was a 1.5T GE Twin Speed. An SPGR structural image was obtained as well as functional images using the following settings: echo time = 51 msec, repetition time = 3 sec, flip angle= 83° . Acquire 27 consecutive axial slice images of the brain with the following dimensions: 192 × 192 mm field of view with a 128 × 128 grid for a total resolution of 1.56 × 1.56 mm and a z-axis resolution of 4.5 mm.

Figure 4. Data collection (fNIRS)



The cap and its placement for fNIRS recordings is shown above. The cap used in this experiment contained a 3 X 5 array of optodes arranged to provide 22 channels of recordings from the left hemisphere. The figure above on the right displays the placement of the cap with a securing chinstrap on the head of a subject with coverage of channels over frontal and temporal lobes.

Figure 5. fNIRS signal optimization

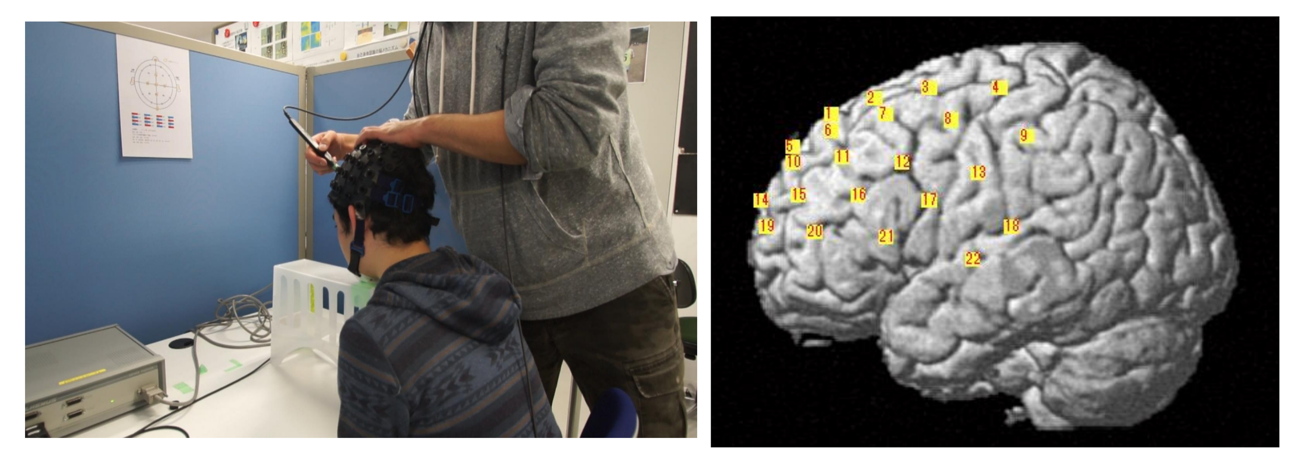


The image above on the left shows how hair was moved from each channel to assure optimal signal quality using a luminescent ear-pick tool. The final optode setup is shown on the right.

Figure 6. DDR gameplay (fNIRS)

The left figure shows how subjects stood and played the game using the block paradigm described previously in Fig. 1. An alternative view of data collection is seen on the right showing raw data being collected in real time.

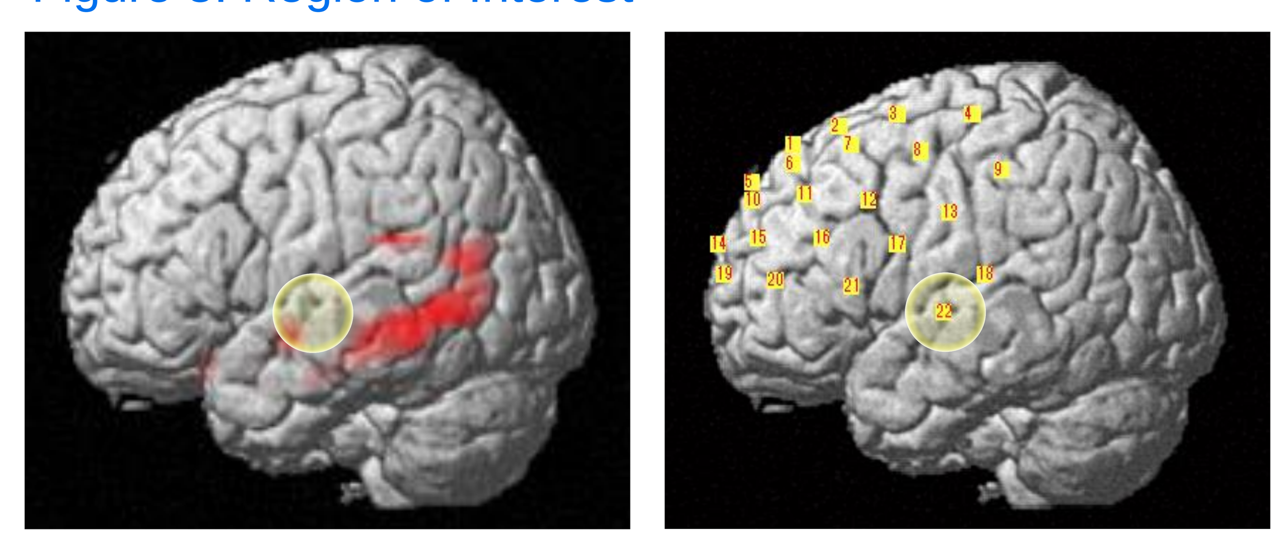
Figure 7. Optode calibration



A magnetic digitizing tool was used to determine placement of 10-20 landmarks on the head and positions of the individual optode channels. The figure on the right shows a sample output of NIRS calibration data. Digitizer data was used to determine the probability of each channel in specific regions of the brain.

Results

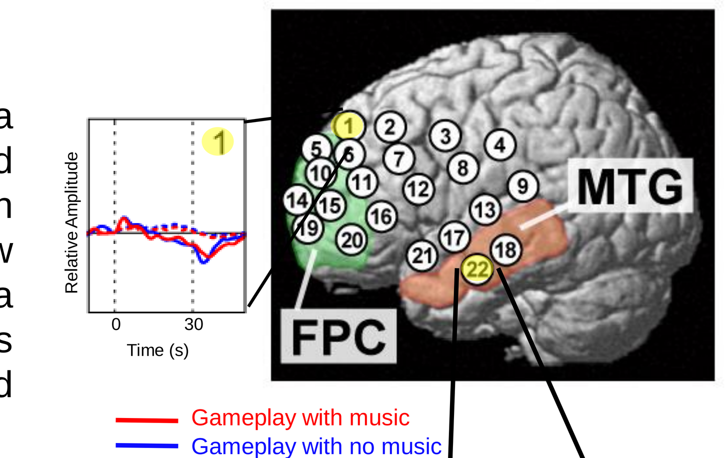
Figure 8. Region of Interest

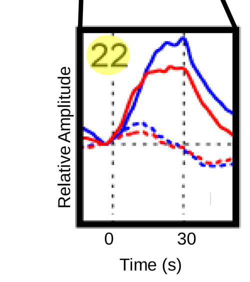


The figure on the left above shows a rendering of the activity (p<0.001) in the temporal lobe. The ROI determined from this activity in the anterior temporal lobe cluster was at MNI coordinate (-52, -4, -8) with a cluster size=126, peak t=5.59. The brain render on the right shows the individual channel locations for a single subject. In this subject channel 22 overlapped the ROI and showed a probability of 0.4129 in the Middle Temporal Gyrus, and 0.47419 in the Superior Temporal Gyrus.

Figure 9. fNIRS data

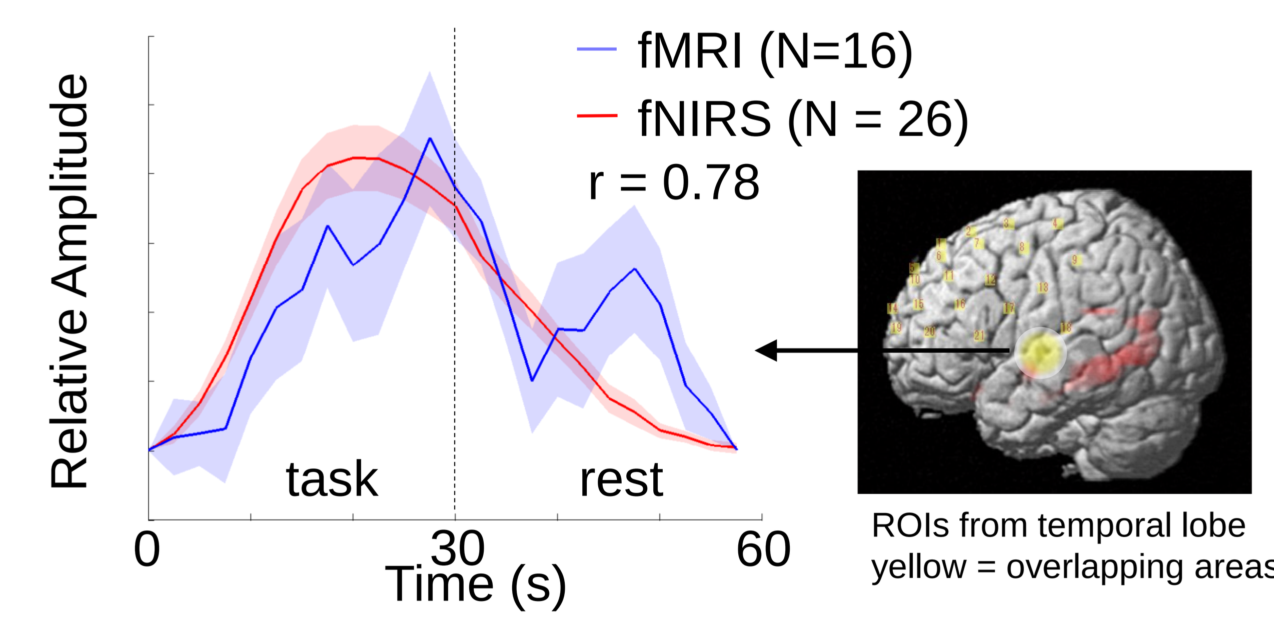
The image on the right shows a brain render with channels and data from a previous publication (Ono et al. 2014). Traces show event-triggered normalized data from the temporal gyrus (channel 22 in this subject) and the frontal lobe (Channel 1).





Solid lines represent oxyhemoglobin signals and dashed lines represent deoxyhemoglobin signals. Red and blue traces represent two variations on gameplay, music and non-music, respectively. Signals from channel 1 serve as a control example to compare with the region of interest (determined from fMRI) in the temporal lobe. Signals in these two regions differ with respect to task-response.

Figure 10. Correlation between fNIRS and fMRI signals)



The results of the experiment indicate activity obtained from integration centers in the superior and middle temporal gyri using functional magnetic resonance imaging (fMRI) have a high correlation to functional near-infrared spectroscopy (fNIRS) signals form the same area in naturalistic version of the task. The figure above shows the normalized and averaged raw data from 16 subjects from the fMRI scanning procedure (blue trace) and the 26 subjects from the fNIRS protocol (red trace). Comparisons were made between the traces by first regressing the fMRI signal to minimize the root mean square difference between the two traces. The resultant correlation coefficient between the two signals was 0.78 and p value for the correlation was 0.03. The semi-transparent overlay represents the standard error of each signal.

Conclusion

The results of this study show that it is possible to obtain highly correlated functional imaging results between fMRI and fNIRS. While fMRI has benefits of high spatial resultion and provides insight into activity in subcortical regions, functional activity as obtained with fNIRS can be captured at a higher temporal resolution and further can be used to record activity from real-world tasks that can not be imaged using fMRI.

Acknowledgements

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