Hemodynamic Response Function from Osteoarthritic Pain using functional Near-Infrared Spectroscopy

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Abstract: Pain-related neural mechanisms are not well understood yet. FNIRS could elucidate the hemodynamic responses under pain stimulation. We present a qualitative perspective on brain response to pain in patients suffering from osteoarthritis.

1. Introduction

Osteoarthritis (OA) is the most common form of arthritis affecting millions of patients worldwide. This degenerative joint disease breaks down the cartilage within the joint, changing the underlying bone. *Functional* Near-Infrared Spectroscopy is a non-invasive, local, optical sensing technique used to measure hemodynamics in human tissues. *f*NIRS was utilized to retrieve the hemodynamic response function (HRF), which models the regional cerebral blood flow changes associated with a task-evoked neuronal activity. The HRF normal activation pattern indicates an increase in oxygenated hemoglobin, while deoxygenated hemoglobin decreases when the task is performed. The purpose was to monitor the brain hemodynamic during pain stimulation in order to recover the HRF profile in a population of adults with symptomatic knee OA pain.

2. Method

2.1 Participants and task description

We included 28 subjects in a single session. For the pain stimulation, moderate-intensity thermal stimuli were applied to the right arm for 20 s followed by a 30 s interval of no stimulation for six trials, which is commonly used in pain-related neuroimaging studies [1]. From a baseline of 32 ºC, the thermode temperature increased by 0.5 ºC per second until the stimulation time was reached or until the participants responded by pressing a button to stop heat stimuli.

2.2 fNIRS measurements and processing

We measured pain-related cortical response using a continuous-wave, multichannel functional near-infrared spectroscopy (fNIRS) imaging system (LIGHTNIRS, Shimadzu, Kyoto, Japan) with three semiconductor lasers at 780, 805, and 830 nm. The probe layout covered the prefrontal cortex (PFC) regions bilaterally and the left somatosensory (SM) cortex (Fig 1, blue lines). The raw optical signals were converted to changes in optical densities and then in concentrations of oxygenated hemoglobin according to the Modified Beer-Lambert law. The quality of the recording of each channel was assessed using a quantitative method that estimates the strength of the physiological cardiac pulsation [2]. After the data quality control process, we discarded five scans due to excessive noise. At the individual level, the cortical hemodynamic responses block-averaged across trials. We considered 5 and 10 seconds before and after the stimulation onset, respectively. Additionally, we obtained an ROI-based average for six ROIs; prefrontal area: PFC_left, PFC_center, and PFC_ right; Somatosensory area: SM_superior, SM_center, and SM_inferior (Fig. 1, red circles). At the group level, we obtained channel-wise and ROI-wise grand averages. Conversion from raw data to hemodynamic parameters and individual and group-level analyses were performed using the software AnalyzIR [3] and Homer2 [4]. All code was executed in MATLAB v2019 (Natick, MA, USA).

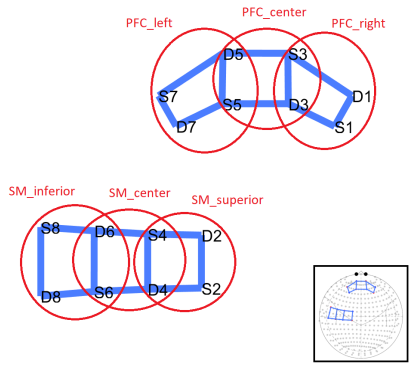
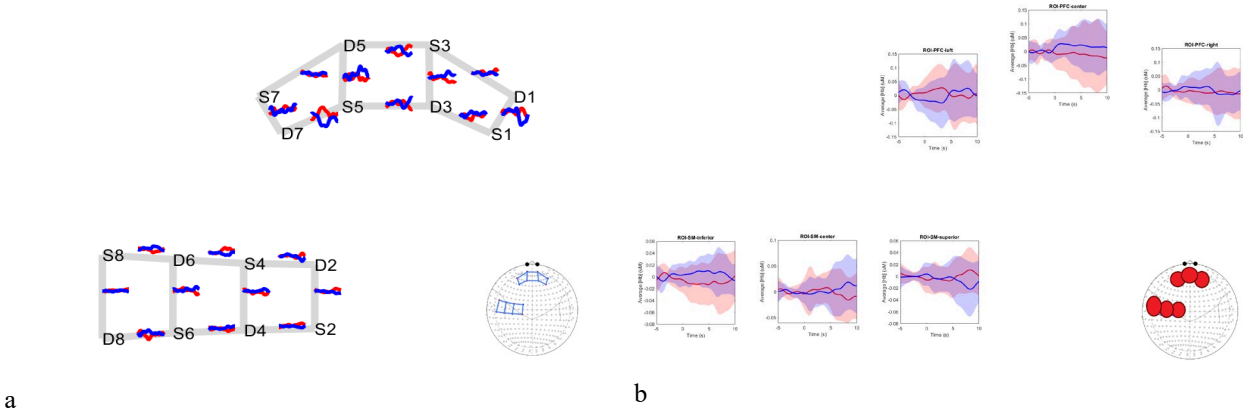


Figure 1. Source (S) and detectors (d) arrangement. Prefrontal cortex and Somatosensory areas were divided into three regions of interest each(PFC_left, PFC_center, PFC_ right; SM_superior, SM_center, and SM_inferior).

3. Results

Most of the PFC channels exhibited a deactivation pattern, an increase in deoxygenated blood, and a decrease in oxygenated blood, and only channel S5-D7 showed a regular activation pattern. From the SM region, we observed a subtle response in S4-D6 (activation), S8-D6 (deactivation), and S6-D8 (deactivation). The activation/deactivation was more prominent in the ROI analysis than the channel-wise analysis. The right and center PFC responses were found as deactivated, while the left-PFC portrayed an activation profile followed by a deactivation profile. We believe that this PFC response (contralateral to the stimulated arm) is caused by compensation for pain tolerance.



a b

Figure 2. Block average response across channels (a) and ROIs (b). ROIs included PFC_left, PFC_center, and PFC_ right; Somatosensory area: SM_superior, SM_center, and SM_inferior.

5. Conclusion

fNIRS was able to observe the brain responses after a pain stimulation. The task-evoked HRFs depicted different shapes rather than a single pattern. Future studies could inform how different experimental factors impact the HRF when studying the brain and pain response. Additionally, the use of fNIRS could help to disentangle the effects of therapies for pain management.

6. Acknowledgments

N.A.V, S.M.H, and L.P. acknowledge that this material was supported by the NSF under Grant Award# 1650536 (I/UCRC BRAIN) and 1757949 (BRAIN REU Site). H.A and H.M acknowledge the support by the Theodore J. and Mary E. Trumble Endowment and NINR grant R15NR018050 and R01NR019051.

3. References

[1] Yucel MA, Aasted CM, Petkov MP, Borsook D, Boas DA, Becerra L. Specificity of hemodynamic brain responses to painful stimuli: a functional near-infrared spectroscopy study. Sci Rep 2015;5:9469.
[2] S. Montero-Hernandez and L. Pollonini, "NIRSplot: A Tool for Quality Assessment of fNIRS Scans," in Biophotonics Congress: Biomedical Optics 2020 (Translational, Microscopy, OCT, OTS, BRAIN), OSA Technical Digest (Optical Society of America, 2020), paper BM2C.5.
[3] Santosa, H.; Zhai, X.; Fishburn, F.; Huppert, T. The NIRS Brain AnalyzIR Toolbox. Algorithms 2018, 11, 73.
[4] Huppert, T.J., Diamond, S.G., Franceschini, M.A. and Boas, D.A. “HomER: a review of time-series analysis methods for near-infrared spectroscopy of the brain.” Appl Opt 2009;48(10): D280-98.