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# Deep BCI of Pain Decoding from fNIRS

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**Abstract.** BCI is a hybrid human artificial intelligence system that promotes physical or cognitive augmentation by artificial intelligence decoding human neurological behavior and feeding it back to humans through artifacts such as robots or computers. This study proposes Deep BCI to alleviate the patient's pain by objectively determining the intensity of pain. This paper deals with the neural decoding of pain, part of Deep BCI. We present a deep learning method to specify pain conditions from the neurological features induced by thermal pain stimulation. We established a thermal stimulation experimental set-up by international standard thermal QST and adopted fNIRS to measure neurological features. An LSTM model was trained to accurately extract fNIRS features associated with the perceived nociceptive pain intensity. As a proof of concept, we applied this trained LSTM model to classify the boundary between pain and non-pain. The accuracy of the classifier was 96.95% for the cold pain vs. non-pain and 96.90% for the hot pain vs. non-pain. Based on this proof-of-concept result, we will develop artificial intelligence that predicts pain levels and applies it to Deep BCI for pain relief treatment.

**Keywords.** Deep BCI, Pain decoding, fNIRS, Thermal QST, LSTM

## 1. Introduction

BCIs are human-in-the-loop systems that are interfaces between humans and artifacts. BCIs are moving beyond applications in neurorehabilitation and cognitive augmentation towards hybrid human artificial intelligence for the co-evolution of human and artificial intelligence [1]. BCI has been mainly focused on neural decoding that grasps the state of perception, cognition, or behavior in the brain. Thanks to the development of neural stimulation technology [2], [3], interest in neural encoding for how information about a given external stimulus is encoded in the population of neurons has been sparked. In particular, the disruptive innovation of artificial intelligence technology represented by deep learning is bringing about a progressive revolution in the neural decoding and encoding paradigm [4], [5]. We would like to exemplify the Deep BCI system for closed-loop pain neuromodulation, as shown in Figure 1. The pain level can be classified/predicted through neural decoding AI from brain signals measured when rating pain for pain stimuli. In addition, according to the current pain status, neural encoding AI optimizes the appropriate stimulation parameters (e.g., location, intensity, frequency, etc.) of stimulation and applies this designated stimulation to the brain to control pain.

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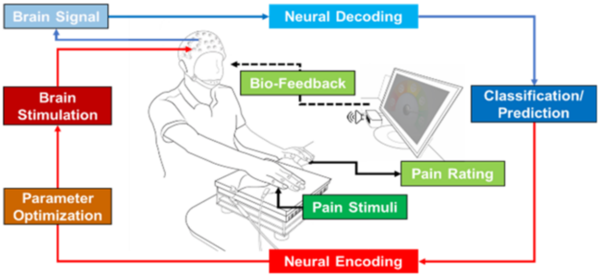


**Figure 1.** BCI for Pain Neuromodulation

This hybrid human-AI platform compares (i.e., bio-feedback) human judgment (i.e., pain rating) with AI's suggestion (i.e., pain classification/prediction). It simultaneously allows humans to actively make decisions (i.e., pain neuromodulation) for AI's assistance (i.e., parameter optimization).

This study only focuses on quantifying pain by decoding brain signals (here, fNIRS) induced by pain stimulation with deep learning. Visual analog scale (VAS) and Numeric rating scale (NRS) can visualize or quantify responses to pain stimuli. McGill pain questionnaire (MPQ) evaluates pain's sensory, affective, and evaluative aspects by selecting standard verbal descriptors ( e.g., burning, throbbing, numbness, etc.) [6]. All of these pain measures focus on subjective assessments of pain. Quantitative sensory testing (QST), on the other hand, quantifies the participants' self-reported sensory experience of applied pain stimuli under standardized testing protocols [7]. This study intends to quantitatively evaluate pain by training a deep learning model that can determine pain or not from functional near-infrared spectroscopy (fNIRS) data in which the subject's pain tolerance and pain threshold are temporally stamped during thermal QST.

## 2. Methods & Results

As shown in Figure 2, a thermal QST battery setup was made according to international standards [8], and the experimental devices were synchronized so that the moment of self-assessment of pain tolerance and pain threshold was recorded in the fNIRS measurement signal. Twenty subjects who agreed after strict approval from IRB (DGIST-20210608-HR-084-10) participated in the experiment and the data of 16 subjects were used for deep learning. The cold and hot stimuli were randomly presented to the left palm, and the pain tolerance and threshold were self-evaluated three times. The evaluation time point was labeled by the fNIRS (51 channels, 10Hz sampling rate) signal formed in the right cerebral hemisphere. In this study, LSTM based model is used to classify pain vs. non-pain from fNIRS signals measured during perceived pain tolerance and threshold. The structure of LSTM based model contains four LSTM layers stacked in serial. After each LSTM layer, a dropout layer was adopted and normalized to the batch after four LSTM layers to alleviate the overfitting problem and improve the performance.

For pain vs. non-pain binary classifier evaluation, the averaged accuracy of binary classification was investigated for five different window lengths (2, 4, 6, 8, and 10 seconds). As expected, the binary classification accuracy increased as the window length increased. It was observed that the increase was slowed at a window length of 4 s or more. Cold and hot pain classification showed the highest accuracy at 6 and 10 seconds, respectively, but no significant difference in accuracy was observed at window lengths of 8 seconds or longer.

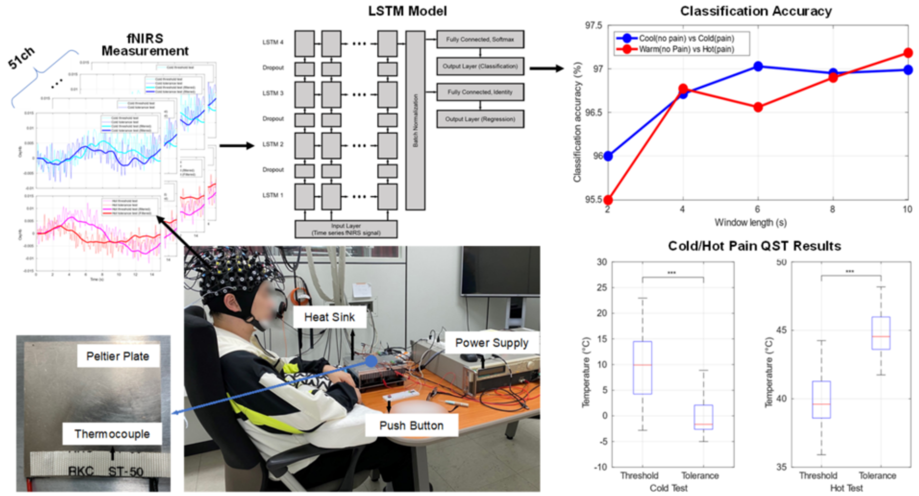


**Figure 2.** Deep BCI of Pain Decoding from fNIRS

## Acknowledgment

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