2. Discussion and Conclusions

The results of this study in Chinese schizophrenics did not replicate the immediate pro-cognitive effects directly after a series to tDCS sessions that we found in the U.S. sample but suggest possible pro-cognitive effects 2 or 4 weeks after treatment. The long term effects to tDCS on cognitive function reported in this and some other studies suggest that some of the positive effects of tDCS may require a consolidation period to improve some aspects of cognitive functions. The fMRI data show that the tDCS treatment had significant effects on brain activation, and the changes in n-back performance in the active tDCS group during fMRI scans suggest increased capacity for working memory performance.

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PROCEEDINGS #34: EFFECT OF SPINAL CORD STIMULATION ON INTRAOPERATIVELY RECORDED EEG IN CHRONIC PAIN PATIENTS

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1. Abstract

Introduction: Spinal cord stimulation (SCS) is routinely used, effective treatment for medically intractable pain syndromes. However, significant subsets of patients remain sub-optimally treated. Plus, the mechanism of action of stimulation is still unknown.
Methods: In order to further our understanding of the electro-physiological changes with respect to stimulation, we recorded 10-channel EEG (electroencephalography) from two chronic pain patients during SCS surgery by using tonic (60Hz-300μs) and high frequency (HF) stimulation (10kHz-30μs). We computed subband powers by normalizing to patient's baseline.
Results: Relative subband power distributions showed that tonic and HF stimulation affect spectral patterns differently compared to their stimulation OFF states. For example, alpha band power was found higher in all channels in P1 and almost all channels in P2 with 10 kHz stimulation while theta band power was only lower in FP1 with tonic stimulation and partially lower on the right side in P2 with HF stimulation.
Conclusion: Our preliminary results might show an underlying pathophysiology and its responses to different stimulation settings in chronic pain patients.

2. Introduction

Chronic pain has been estimated to affect about 100 million adult Americans. Treatment of chronic pain remains suboptimal, with 51% of patients reporting having little to no control over their pain [1]. While SCS can be used effectively in many patients [2-4], significant subsets of patients remain sub-optimally treated [3]. In patients, benefit has been shown with higher frequencies as opposed to continuously given impulses (tonic) [5-6]. We are unclear how these neuromodulators work to control pain. Further, it remains to be elucidated whether changing the way the electrical impulse is delivered can change how pain is felt.
Our understanding of the effects of chronic pain or the different SCS waveforms on EEG patterns are limited. Chronic pain studies showed higher spectral power in theta and beta bands [7-8]. The patients who were taking centrally acting pain medications showed similar patterns to that of non-medication taking patients. After central lateral thalamotomy, the differences in the theta bands normalized along with reduction in pain perception [8-9]. It was also shown that the peak activity in chronic pain patients with spinal cord injury was in theta range while it was in alpha range in non-pain patients with spinal cord injury [10].
Here, we explore effects of tonic and 10kHz-HF stimulation on EEG recordings during surgery. The purpose of this pilot study is to clarify how this stimulation patterns may affect electrophysiological activity in the cingulate, prefrontal, motor and sensory cortex in chronic pain patients with back pain and associated radicular symptoms.

3. Methods

EEG signals were recorded from 2 patients with chronic pain who were undergoing thoracic SCS surgery. The experimental protocol was approved by the Institutional Review Board of Albany Medical College. Both patients provided written informed consent for study participation. Surgeries were performed in asleep using total intravenous anesthesia as done routinely at our center to allow for intraoperative neuromonitoring (ION).
EEG recordings through 10 channels were collected by using needle electrodes. Data acquisition was performed with 128 Hz sampling frequency using the Cascade PRO (Cadwell, Kennetwick, MA) monitoring system. EEG recording started when the optimal current and the contact pair were determined by gradually increasing current from 0 mA to 10 mA with 60 Hz frequency and 300 μs pulse width as per our ION protocol [11]. Then, 1-min baseline was recorded while the stimulation was OFF. Immediately after, lead was stimulated from the optimal contact pair for 40 s by using tonic (60Hz-300μs) and HF (10kHz-30μs), respectively. Each stimulation trial was separated by 30-s OFF period.
All data were analyzed offline in Matlab (Mathworks, Natick, Massachusetts). A modified Welch periodogram method was used to map the signals to the frequency domain. Subband power changes relative to baseline were computed in theta (4-7 Hz), alpha (8-12 Hz), beta (13-30 Hz), and gamma (35-55 Hz) bands. The relative powers which show the power changes with respect to baseline were represented in decibel scale (dB).

4. Results

We analyzed 10-channel EEG data in 2 chronic pain patients, P1 and P2, age 64 and 48 years, respectively. Both patients were implanted with paddle electrodes placed over the T9-10 interspace (Nevro Corp, CA). The distribution of relative EEG powers, including topographical maps, for tonic (blue) and HF (red) are shown in **Fig.1**. Theta power in both trials was found increased in almost all channels in P1 (**Fig.1.A**). Channel FP1 showed no theta change by tonic stimulation. HF stimulation increased alpha power in all channels while tonic stimulation slightly increased the alpha power in F1, FP1, CP3, CP4, and T8. Considering that the alpha power decreases in chronic pain patients compared to healthy subjects or medicated pain patients [7,10], this enhancement induced by HF might be a therapeutic effect. Both tonic and HF stimulation increased the beta and gamma powers in various degrees in almost all EEG channels. The highest amount of change was found on T8 in both trials.
Fig.1.B demonstrates the power changes in P2. The patterns of relative theta power were found different in P2. HF induced a decrease in theta power mostly on the right side. Unlikely, tonic stimulation induced no change in theta power on this side. Patterns in alpha range in response to HF were various. Mostly the frontal regions showed positive changes in alpha power with stimulation and the increase was higher with HF. The most dramatic difference between tonic and HF stimulation was found in beta and gamma band powers in P2. HF increased beta power in all channels with a similar degree while tonic stimulation decreased it in various amounts. Similarly, the change in gamma power was mostly positive in HF and negative in tonic stimulation.

5. Discussion and Conclusion

In the current study, we found the peak activity in P1 at the alpha range with HF stimulation while it remained at theta range with tonic stimulation. On the other hand, peak activity in P2 was noted at beta range with HF stimulation. The increased alpha activity in this patient was noted in the frontal regions with HF stimulation. It has been shown that a shift towards theta peak frequencies is a hallmark of chronic pain [8-9]. Thus, the demonstrated shift towards higher, alpha, frequencies may be the first

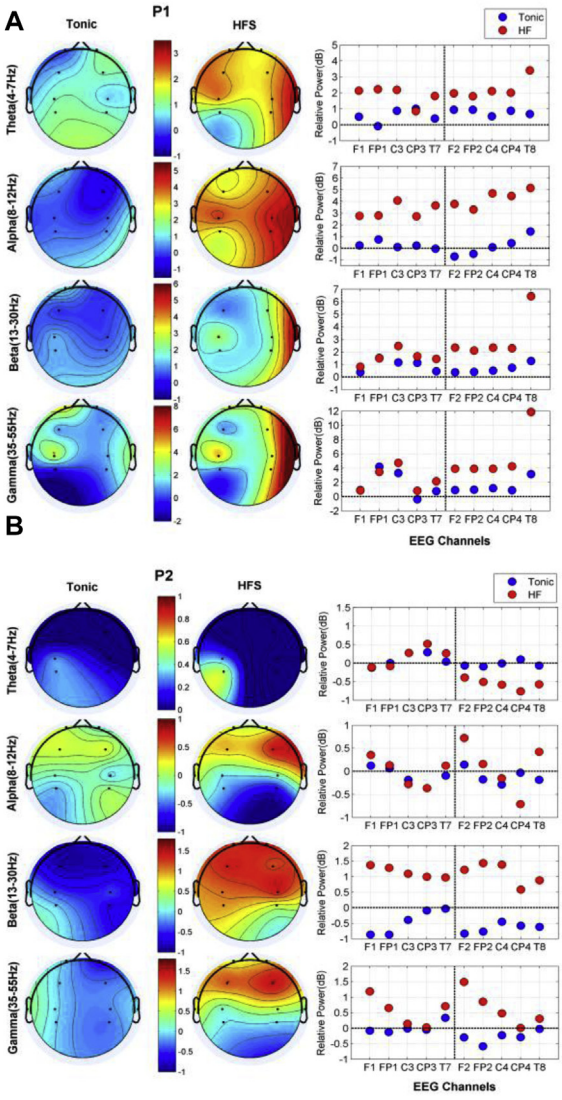

Fig. 1. Relative subband power distribution across channels in **(A)** P1, **(B)** P2. Left column shows the topographical maps. Color bar indicates the power changes in dB scale. Right column shows the individual power values in response to tonic (blue) and HF (red) stimulation. Values above and below the zero-line demonstrate increase and decrease relative to baseline, respectively.

indicator of pain relief facilitated by HF stimulation [8]. Additionally, we demonstrated topographical differences between tonic and HF stimulation over many different sites indicating pain has diffuse effect and some cortical areas may be more contributory to these differences [10]. We might speculate about the effect of anesthesia which characteristically replaces the faster brain rhythms (alpha and beta) by slower activity (delta and theta) [12]. However, we investigated the power changes relative to their baseline and we didn't observe uniform changes in the subband powers in these patients.

Postoperative pain evaluation, 6 weeks following the SCS surgery, indicated that pain level in P1 was 3/10 while this was 7/10 in P2 with suboptimal pain relief. Considering the elevated alpha power indicates a NO/less-pain state, HF-induced positive changes in alpha power might be correlated to stimulation-responsive pain state in P1.

Our preliminary results support the possibility that different stimulation patterns affect the electrophysiological activity differently in various cortical regions. Such differences might account for the variability in pain suppression in patients with chronic pain treated with SCS. Why do we see these spectral changes in these locations? What are the major differences between 60 Hz and 10 kHz stimulation? Why do we observe asymmetrical responses with some stimulation settings? These questions need to be studied in detail with larger subject populations.

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PROCEEDINGS #35: INFLUENCE OF MODEL EXTENT IN FORWARD SIMULATIONS OF TDCS: TOWARDS STANDARDIZING MODEL EXTENT

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1. Abstract

Computational models based on MRI are commonly used to predict brain current flow due to transcranial direct current stimulation (tDCS). The predictions from these models not only inform planning optimal stimulation strategies but also to analyze stimulation results on a post-hoc basis. Given that these models are based on individual MRI data, the field of volume (FOV) considered have been naturally restricted to the MRI volume collected. As a result, the model extent considered across studies has varied considerably – starting from head vertex down to level of the eyes, whole brain, jaw, whole head, etc. Further, with the availability of whole-body models, it raises the question whether model FOV should extend to even lower body regions to accurately predict cortical current flow. This uncertainty on the model extent that needs to be considered potentially impacts efforts on model validation and comparison across modeling studies. The objective of this study was therefore to determine the FOV beyond which, computed cortical current flow magnitude would asymptote. We considered multiple models derived from a single whole-body