様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

科研費 KAKENHI

科学研究費助成事業　　研究成果報告書

令和　４年　６月１７日現在

機関番号：９４３０１
研究種目：基盤研究(C)（一般）
研究期間：2018～2021
課題番号：１８Ｋ１２０２４

研究課題名（和文）Performance related changes in Resting State Neural Activity and Connectivity induces by tDCS

研究課題名（英文）Performance related changes in Resting State Neural Activity and Connectivity induces by tDCS

研究代表者

カラン　ダニエル（DANIEL, Callan）

株式会社国際電気通信基礎技術研究所・脳情報通信総合研究所・主幹研究員

研究者番号：７０３７４１１３

交付決定額（研究期間全体）：（直接経費）　　3,400,000円

研究成果の概要（和文）：本研究の目的は、経頭蓋直流電気刺激(tDCS)により誘発される脳活動の変化が、様々な課題における行動パフォーマンスの円滑化に関連していることを明らかにすることである。視覚探索/ギター即興演奏/飛行機着陸の3つの課題において、実刺激または偽刺激条件下でフィードバックを行いながら、各課題の前後に約30分間のtDCSを適用した。tDCSによる全体的なパフォーマンス促進は見られなかったものの、一部においてパフォーマンス促進に関連する脳活動の興味深い変化が見出さた。tDCS実刺激群では、変調された脳活動の程度に基づいて行動パフォーマンス促進を予測できたが、tDCS偽刺激群では予測することができなかった。

研究成果の学術的意義や社会的意義
一般的に、経頭蓋直流電気刺激(tDCS)は、様々な知覚、運動、認知課題のパフォーマンスや学習促進に有効であると考えられているが、本研究によりパフォーマンスの促進については差異があることがわかった。パフォーマンスの促進は脳活動の識別可能な変調によって特徴付けられることから、当該促進に関与する脳回路を特定したという点で学術的に重要である。また、学習効果向上ために個人特有の刺激パラダイムを調節したり、認知障害や精神障害等の治療に用い得ることから、社会的意義がある。tDCSの限界と、行動パフォーマンス促進の成功に相関する基礎的な脳活動の理解を深めることで、より良い新たなtDCSの実施が可能となる。

研究成果の概要（英文）：The primary goal of the research was to determine the changes in brain activity induced by transcranial direct current stimulation (tDCS) that are related to facilitation in behavioral performance during training on various tasks. The three tasks that are studied includes 1. A visual search task, 2. A guitar improvisation task, and 3. An airplane landing task. All of these studies employed a pre- and post- training session in which tDCS was given for approx. 30 minutes while feedback training was employed in either real stimulation or sham stimulation conditions. Even though we did not find an overall performance facilitation by tDCS, the results of these studies did find interesting changes in brain activity in some individuals that were related to facilitating performance. Essentially behavioral performance facilitation could be predicted in individuals in the tDCS stimulation group based on the degree of modulated brain activity but could not be predicted in the tDCS sham group.

研究分野：脳科学

キーワード：tDcs　fMRI　EEG　Resting　State　Attention　Learning

様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９（共通）

１．研究開始当初の背景

Transcranial direct current stimulation (tDCS) has been used extensively in both research and clinical settings to improve performance and learning on various perceptual, motor, and cognitive tasks as well as for treatment for various mental and neurological disorders (Brunoni et al., 2014; Coffman et al., 2014). Brain stimulation methods such as tDCS have also been proposed to be able to test causal relationships between brain processing and behavior (ref). TDCS involves delivering prolonged (~10- 20 min), low intensity electric current (1-2mA) to the scalp usually through a pair of stimulating electrodes (anodal positive, cathodal negative). Anodal tDCS (a-tDCS) generally increases neuronal excitability and promotes mechanisms involved in LTP, whereas, cathodal stimulation generally reduces neuronal excitability and promotes mechanisms involved in LTD (Nitsche and Paulus, 2000; Callan and Perrey, 2018). Despite the considerable number of studies showing modulatory effects of tDCS on human behavior there is still dispute of its efficacy in terms of its reliability to replicate results (Horvath et al., 2015; However see Antal et al., 2015 for rebuttal). Studies using fMRI to investigate concurrent and after effects of tDCS on resting state and task related brain activity and connectivity have shown considerable variability in their results dependent on presence or absence of a task, stimulation site, polarity of stimulation, amplitude of stimulation, timing of stimulation, and nature of the task under investigation. The general findings of this tDCS-fMRI research include the following: tDCS influences brain networks with regions both proximal and distal to the stimulating electrodes including those in subcortical regions; Resting state activity and connectivity are modulated dependent on the presence of a task prior to recording resting state activity; Changes in resting state brain networks induced by tDCS are task dependent (Callan et al., 2016).

２．研究の目的

The goal of the proposed research was to determine the tDCS induced changes in resting state and task related brain activity and connectivity (recorded during concurrent tDCS-fMRI and/or with EEG pre- and post- tDCS) that predict enhancement in behavioral performance. It is hypothesized that tDCS of task relevant brain networks increases processing efficiency by reducing the variability in the multiple degenerate neural networks that could potentially be used to accomplish the same task.

３．研究の方法

Experiment 1.

The participants consisted of 28 adults separated evenly into tDCS stim and tDCS sham groups. We used functional magnetic resonance imaging (fMRI) concurrently with tDCS stimulation (1 mA, 30 minutes duration) using a visual search task simulating real world conditions (Identify specific red truck in city with distractor vehicles present). The experiment consisted of three fMRI sessions: pre-training (no performance feedback), training (performance feed- back which included response accuracy and target location and either real tDCS or sham stimulation given), and post-training (no performance feedback). The right posterior parietal cortex was selected as the site of anodal tDCS based on its known role in visual search and spatial attention processing (For more details see: Falcone, Wada, and Callan, 2018).

Experiment 2.

The participants consisted of 54 adults separated evenly into 4 groups. There were two tDCS stim groups (one for each of the type of training condition: ahead of the beat = microtiming deviation group, on the beat = control group) and tDCS sham groups. The participants took part in three tasks pre and post training: 1. Improvisation task, 2. Ahead of the beat task, 3. On the beat task. EEG was recorded during the pre- and post sessions. tDCS was give during the training session. The improvisation task involved playing music on the guitar with a specific background track music (BTM). The ahead of the beat involved playing the guitar with timing before the perceived beat rhythm, whereas the on the beat task involved playing the guitar with timing on the perceived beat rhythm. See Figure 1 below for depiction of the experimental methods:

Experiment 3.

The participants consisted of 26 adults separated evenly into tDCS stim and tDCS sham groups. This experiment consisted of three runs. Each run contains an eight-minute resting state scan followed by a twenty-minute task measurement. Each task part of the run has twenty trials of pseudorandom balanced order of the eight dual-task conditions. The three-by-two design has three factors: easy runway vs hard runway, no wind versus moderate wind, and audio response versus audio ignore. The two groups of subjects: control, with sham tDCS, and stim, with thirty minutes of tDCS. The three runs are labeled as pre-training, training, and post-training. Both conditions have identical pre- and post-training runs; the difference is only whether the subjects receive sham or real tDCS. During the pre- and post-training runs, subjects do not receive feedback on their performance on the dual tasks. During the training block, both groups receive feedback on their landing and auditory response results. Participants controlled a single-seat propeller plane (pitch, roll, and yaw by joystick) on final approach to runway.

The auditory task consisted of audio stimuli being played during each trial. Each stimulus was presented an average of once per two seconds, and consisted of a pseudorandom callsign containing a basic color and number combination (i.e. Blue 4, Green 9). Subjects were instructed to memorize the parity (even or odd) of the number following every “Red” stimulus, and respond with a button press to each following red callsign number based on whether the parity was a match or mismatch (i.e. Red 5 followed by Red 7 is a match, but Red 2 is a mismatch). Responses were required in half of all trials based on an indication visually provided to participants, but auditory stimuli played every trial regardless.

Participants were outfitted with a Neuroelectrics Starstim high definition tDCS with three electrodes to localize stimulation to the 10-20 location AF8 over the right DLPFC. Thirty minutes of stimulation at 1.5 mA was provided during the second session for the stim group, whereas the sham group only received 30 seconds of ramp-up stimulation. The head cap remained on participants throughout the entire experiment to allow them to stay within the MRI.

４．研究成果

Experiment 1.

Our results identified a region in the right precentral gyrus, known to be involved with visual spatial attention and orienting, that showed tDCS induced task related changes in cortical excitability that were associated with individual differences in improved performance (Fig. 2). This same region showed greater activity during the training session for target feedback of incorrect (target-error feedback) over correct trials for the tDCS stim over sham group indicating greater attention to target features during training feedback when trials were incorrect. These results give important insight into the nature of neural excitability induced by tDCS as it relates to variability in individual differences in improved performance shedding some light on the apparent lack of reliability found in tDCS research (Falcone, Wada, Parasuraman, Callan, 2018).

Experiment 2.

In experiment 2 we attempted to investigate how tDCS may enhance creativity in terms of guitar improvisation performance by enhancing training performance on a microtiming task (ahead of the beat) relative to control (on the beat) in conjunction with tDCS stimulation to the left dorsal premotor cortex. It was conjectured that perception and action of variability in timing (microtiming deviation) is important for music improvisation performance. While the results of the experiment did show a significant improvement in improvisation performance in the group that received microtiming deviation training (ahead of the beat) (see Figure 3 below), there were no significant differences between the sham group and the group that received tDCS stimulation during training. This work has been submitted for publication (Sasaki, Iverson, Callan, submitted). Further analysis is being conducted to determine if the resting state activity (EEG) post relative to pre training did show a correlation with improved guitar improvisation performance that was present for the tDCS stimulation group over the sham group in the dorsal premotor cortex (site of stimulation) or regions connected to it.

Experiment 3.

Experiment 3 involved the use of tDCS inside of the fMRI during a dual-task flight simulator landing and audio identification experiment. The details of this novel paradigm were as follows: ‘A three-block design was created to collect data pre-training, during feedback training, and post-training while being recorded in an fMRI. The dual task consists of 30–45 s trials landing a plane on one of two runways, indicated by an arrow displayed on the simulator screen, while simultaneously responding to auditory stimuli played constantly during each trial with button presses. The landing task is presented at two difficulty levels in pseudorandom balanced order, modulated by wind speed and direction. Two auditory conditions, response and control (no response), are used for a two by two design. For the feedback training, subjects are provided with relevant measures of how well they are able to land on the specified runway as well as their accuracy in the auditory task. Subjects will be randomly assigned to tDCS stimulation or sham groups, with stim receiving 30 min of 1.5 mA high definition-tDCS to the right ventrolateral prefrontal cortex during the training block’(Mark, Ayaz, and Callan, 2021). The analysis of behavioral data does show some difference in post relative to pre landing performance for the group with training with tDCS stimulation over sham stimulation (decrease in landing performance contrary to predictions – see figure below). The analysis of the fMRI data (both resting state and task related activity) is ongoing and should be finished soon and submitted for publication. It is expected that significant differences will be found in brain regions undergoing tDCS stimulation that are related to landing performance improvements for the stim over sham groups.

References:

Falcone, B., Wada, A., Parasuraman, R., Callan, D. (2018). Individual differences in learning correlate with modulation of brain activity induced by transcranial direct current stimulation. *PLoSOne 13*(5):e0197192. Doi: 10.1371/journal.pone.0197192

Mark, J., Ayaz, H., Callan, D. (2021). Developing a tDCS-Enhanced Dual-Task Flight Simulator for Evaluating Learning. In: Ayaz, H., Asgher, U. (eds) Advances in Neuroergonomics and Cognitive Engineering. AHFE 2020. Advances in Intelligent Systems and Computing, vol 1201. Springer, Cham. https://doi.org/10.1007/978-3-030-51041-1_21

Sasaki, M., Iverson, J., Callan, D. (Submitted). Music improvisation performance can be enhanced by improving processing of rhythmic microtiming. Scientific Reports (Under Review).

５．主な発表論文等

〔雑誌論文〕　計1件（うち査読付論文　1件／うち国際共著　1件／うちオープンアクセス　1件）

１．著者名 Brian Falcone, Atsushi Wada, Raja Parasuraman, Daniel Callan	４．巻 13(5)
２．論文標題 Individual differences in learning correlate with modulation of brain activity induced by transcranial direct current stimulation	５．発行年 2018年
３．雑誌名 PLOS One	６．最初と最後の頁 1-25
掲載論文のDOI（デジタルオブジェクト識別子） 10.1371/journal.pone.0197192	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 該当する

〔学会発表〕　計3件（うち招待講演　2件／うち国際学会　2件）

１．発表者名 Daniel Callan and Frederic Dehais
２．発表標題 Brain processes underlying airplane landing performance.
３．学会等名 11th International Conference on Applied Human Factors and Ergonomics（招待講演）
４．発表年 2020年

１．発表者名 Callan, D., Iversen, J., Dehais, F.
２．発表標題 Independent modulators of ongoing neural activity predict future perceptual performance.
３．学会等名 25th Annual Meeting of the Organization of Human Brain Mapping（国際学会）
４．発表年 2019年

１．発表者名 Daniel Callan
２．発表標題 Exploring the neural correlates of inattentional deafness using multimodal brain imaging.
３．学会等名 2nd International Neuroergonomics Conference: The Brain At Work And In Everyday Life（招待講演）（国際学会）
４．発表年 2018年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

－

6．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考
研究分担者	和田　充史 (WADA Atsushi) (10418501)	国立研究開発法人情報通信研究機構・脳情報通信融合研究センター脳機能解析研究室・主任研究員 (82636)	

7．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

8．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関