Preliminary Study of Neurophysiological Correlates of Movement Quality in Stroke Rehabilitation

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Stroke is one of leading causes of disability (Gorelick, 2019) and by 2047, 2.4% of the EU population is estimated to suffer from stroke and its consequences (Wafa et al., 2020). Due to different levels of impairment including muscle weakness, loss of inter-joint coordination, and muscle tone changes (Kwakkel et al., 2017), there is an urgent need for novel methods of rehabilitation to improve the functional outcomes for stroke survivors. A promising new direction is the use of EEG-based brain-computer interface (BCI) systems for stroke rehabilitation (Grosse-Wentrup et al., 2011), upgrading the general BCI protocols in neurorehabilitation providing patients with feedback on brain activity that occurs as a result of the intent to imagine or attempt to execute a movement (Gomez-Rodriguez et al., 2011; Ang et al., 2013). In this study, we explore the question of whether patients can also be provided with feedback on the *quality* of their imagined or attempted movements. Towards this end, we recorded EEG data from two stroke patients during physiotherapy, had an occupational therapist score the quality of each movement, and then analyzed correlations between the amplitudes of canonical EEG rhythms and movement quality. Alterations in brain activity after stroke are widely reported in the literature, such as changes in the intra- and inter-hemispheric interactions and functions (Graziadio et al. 2012). More specifically, it is well established that mu and beta rhythms, frequency bands related to motor tasks that oscillate over the sensorimotor cortex (Pfurtscheller et al., 1997), can be detected by motor execution and imagery in healthy subjects (Pfurtscheller et al., 2006). We thus hypothesized that mu rhythm desynchronization will be proportionately correlated with the quality of movement as judged by the expert.

Due to COVID-19 restrictions we only included two chronic patients after left ischemic stroke. The level of motor impairment was assessed by a therapist with the Fugl-Meyer assessment. A five-point scale was implemented for categorizing the quality of each movement during therapy, using the Goal Attainment Scaling (GAS) framework, which is commonly used in rehabilitation as a mathematical technique for quantifying the achievement of goals set (Krasny-Pacini et al., 2013). Individual GAS scores were done for all movements before the first recording (1 - 60% movement with compensation, 5 - 100% movement without compensation. The investigated movements included shoulder ante-flexion, shoulder abduction, shoulder abduction+ante-flexion, and elbow flexion+adduction, targeting the rotator cuff and upper arm muscles. The movements were done with the support of an adjustable table, where the arm was in an anti-gravitational position that supported movements in the horizontal plane.

The data was recorded with a wireless BrainWaveBank EEG system with 16 electrodes, resting-state included. Data collection consisted of five 60 minutes sessions. A 15-minute upper limb mobilization and warm-up exercises were done each recording to enhance flexibility led by the therapist were included. Each session was composed of three blocks of 40 movements, the blocks being separated by a rest period of about 8-12 minutes. The participants looked at a fixation cross on a screen as a reference period to use as a baseline. The order of movements was semi-randomized for each block, such that each movement type may not occur more than two times in concurrence. For the sake of estimating event-related changes in the bandpower frequency, the inter-movement interval between consecutive movements was 14 seconds - a fixation cross to obtain the baseline was shown for two seconds, followed by written movement instructions and an auditory cue to begin the movement one second after. A period of five seconds was provided for the movement execution followed by a rest period of six seconds. This resulted in 150 trials of each movement type for each participant.

For the data analysis, the continuous raw EEG data was divided into epochs of six seconds (one second before movement onset until 5 seconds after movement onset), and divided into the four different movement types. The epoched signals were then transformed from the time domain into the frequency domain by applying fast Fourier transform (FFT) using the Hann window, in order to calculate the log-bandpower (from 0.5 to 20 Hz) of each epoch. The bandpower signals were averaged over all channels (three bad channels were excluded for patient 2) and then divided and averaged based on their movement quality score. Figure 1 shows the log-bandpower plot for patient 1, Figure 2 for patient 2, respectively. In order to correlate the movement execution with its movement quality score, statistical analysis was conducted with the permutational multivariate analysis of variance (PERMANOVA), using the log-bandpower in the range of 6.5-9.5 Hz for patient 1 and 7-11 Hz for patient 2, respectively.

In contrast to our hypothesis, task-induced changes in mu rhythm showed no significant correlation with movement quality. Rather, we found a significant negative correlation ($p = 0.038$ and $p <= 1e-5$ for patients 1 and 2, respectively) between global alpha power and the quality of movement as judged by the expert for both patients over all channels for the timeframe of one second before movement onset until 5 seconds after movement onset. These results suggest that the background brain state may affect the movement quality during stroke rehabilitation. Alpha oscillations are generally associated with attentional processes (Klimesch, 1999, Carp and Compton, 2009; Sharma and Singh, 2015) and have recently been linked to the inhibition of task-irrelevant brain processes (Jensen & Mazaheri, 2010). Consistent with our results, greater alpha power decrease has been shown in subjects who performed a motor task more successfully compared to those subjects whose alpha power remained more similar to the baseline (Gong et al., 2020). In conclusion, our results indicate that BCI-based stroke rehabilitation systems may be further improved by providing patients with feedback on their global alpha-power to help them attain a state of mind that is beneficial for motor retraining. Currently we are preparing a larger scale study to further investigate these results, with accompanying EMG data and EEG comparison of lesioned/non lesioned hemisphere.

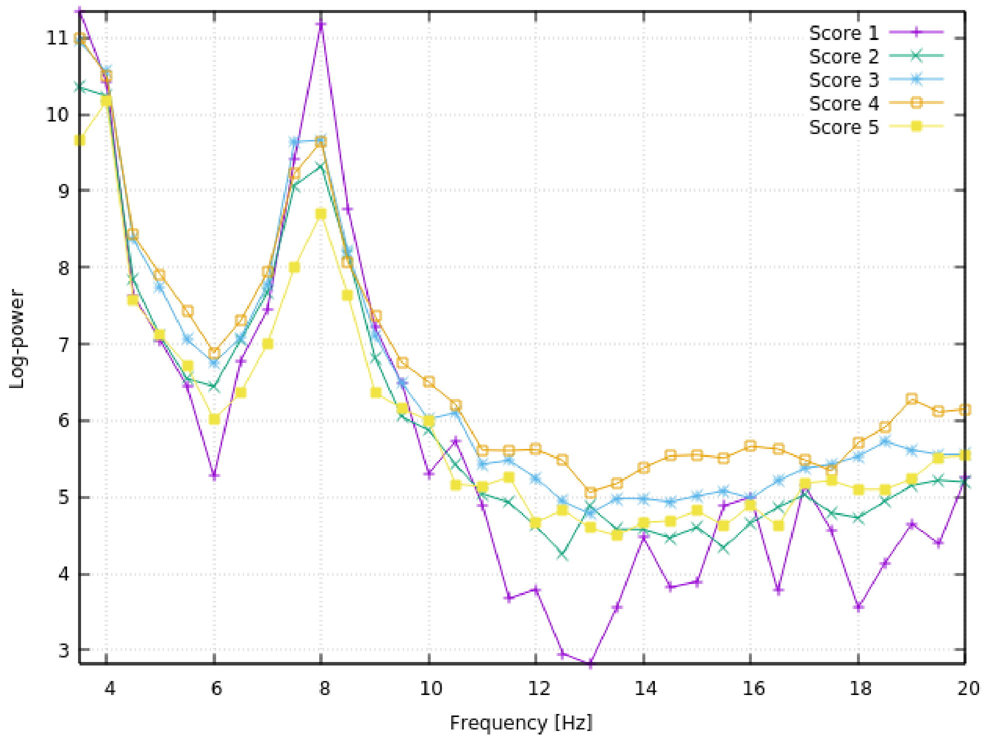

Figure 1. Log-bandpower of patient 1 during movement execution in the frequency range of 4-20 Hz, averaged over all channels and epochs, divided into the five movement quality scores (1= worst movement execution, 5 = best movement execution).

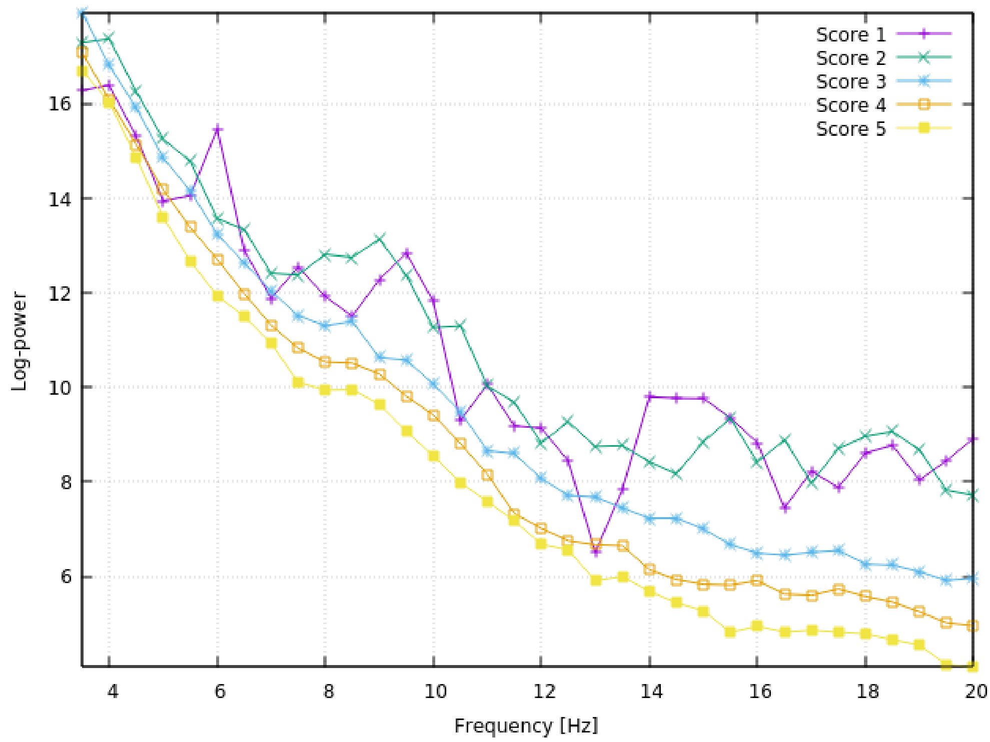

Figure 2. Log-bandpower of patient 2 during movement execution in the frequency range of 4-20 Hz, averaged over all channels and epochs, divided into the five movement quality scores (1= worst movement execution, 5 = best movement execution).

References:

Ang, K. K., Guan, C., Chua, K. S. G., Ang, B. T., Kuah, C. W. K., Wang, C., ... & Zhang, H. (2011). A large clinical study on the ability of stroke patients to use an EEG-based motor imagery brain-computer interface. *Clinical EEG and Neuroscience*, *42*(4), 253-258.

Carp, J., & Compton, R. J. (2009). Alpha power is influenced by performance errors. Psychophysiology, 46(2), 336-343.

Jensen, O., & Mazaheri, A. (2010). Shaping functional architecture by oscillatory alpha activity: Gating by inhibition. *Frontiers in Human Neuroscience, 4,* Article 186. https://doi.org/10.3389/fnhum.2010.00186

Klimesch W. EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. Brain Res Brain Res Rev. 1999 Apr;29(2-3):169-95. doi: 10.1016/s0165-0173(98)00056-3. PMID: 10209231.

Krasny-Pacini, A., Hiebel, J., Pauly, F., Godon, S., & Chevignard, M. (2013). Goal attainment scaling in rehabilitation: a literature-based update. Annals of physical and rehabilitation medicine, 56(3), 212-230.

Gomez-Rodriguez, M., Grosse-Wentrup, M., Hill, J., Gharabaghi, A., Schölkopf, B., & Peters, J. (2011, June). Towards brain-robot interfaces in stroke rehabilitation. In *2011 IEEE International Conference on Rehabilitation Robotics* (pp. 1-6). IEEE.

Gong, A., Nan, W., Yin, E., Jiang, C., & Fu, Y. (2020). Efficacy, Trainability, and Neuroplasticity of SMR vs. Alpha Rhythm Shooting Performance Neurofeedback Training. *Frontiers in human neuroscience*, *14*, 94. https://doi.org/10.3389/fnhum.2020.00094

Gorelick, P. B. (2019). The global burden of stroke: persistent and disabling. The Lancet Neurology, 18(5), 417-418.

Graziadio, S., Tomasevic, L., Assenza, G., Tecchio, F., & Eyre, J. A. (2012). The myth of the 'unaffected' side after unilateral stroke: Is reorganization of the non-infarcted corticospinal system to re-establish balance the price for recovery?. Experimental neurology, 238(2), 168-175.

Grosse-Wentrup, M., Mattia, D., & Oweiss, K. (2011). Using brain-computer interfaces to induce neural plasticity and restore function. *Journal of neural engineering*, *8*(2), 025004.

Pfurtscheller G., Neuper C., Andrew C., Edlinger G. (1997). Foot and hand area Mu rhythms. International Journal of Psychophysiology 26(1-3):121-35.

Pfurtscheller G, Brunner C, Schlogl A, Lopes da Silva FH. Mu rhythm (de)synchronization and EEG single-trial classification of different motor imagery tasks. NeuroImage 2006; 31(1): 153-159

Sharma, A., & Singh, M. (2015, September). Assessing alpha activity in attention and relaxed state: An EEG analysis. In 2015 1st International Conference on Next Generation Computing Technologies (NGCT) (pp. 508-513). IEEE.

Wafa, H. A., Wolfe, C. D., Emmett, E., Roth, G. A., Johnson, C. O., & Wang, Y. (2020). Burden of stroke in Europe: thirty-year projections of incidence, prevalence, deaths, and disability-adjusted life years. Stroke, 51(8), 2418-2427.