S10_1. Clinical Studies and Neuroimage Analysis of Brain-Computer Interface for Stroke Rehabilitation


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Recently, Brain-computer interface (BCI) technology has been actively investigated to provide a new alternative way of rehabilitation to help stroke survivors to restore motor function by inducing activity-dependent brain plasticity. Worldwide, stroke is one of the leading causes of severe disabilities. About one-third of stroke survivors need various forms of rehabilitation. Among these, upper limb weakness and loss of hand function are among the most devastating types of disabilities. Limitations in current physiotherapy and occupational therapy techniques include: (i) difficulties in rehabilitation for the severely paralyzed arm and hand which are often treated with passive modalities, (ii) difficulties in achieving intensive rehabilitation and high repetitions in those with moderate to severe upper extremity paralysis, (iii) problems in motivating and sustaining patient interest in repetitive exercises, (iv) therapy is often perceived to be boring due to lack of immediate biofeedback.

The hypothesis of using BCI for stroke rehabilitation is built on the following basis: (1) motor imagery activates primary motor cortex, pre-motor cortex, and possibly some other parts of the brain which are responsible for motor control, therefore rehabilitation using motor imagery can lead to motor recovery; (2) BCI provides a contingent feedback for stroke patients which helps reinforce the neural pathway of motor control; (3) real-time feedback to patients provides motivation due to visual/auditory/haptic feedback; (4) combination of BCI with mechanical stimulation (eg. robotics) provides motor/sensory feedback which is beneficial.

We have conducted three pilot clinical studies involving 66 stroke patients, where we investigated how BCI was used in conjunction with other devices (robotics, haptic, and TDCS) to help hemiplegic stroke patients in performing upper limb rehabilitation. In this talk, we will present the following results from the studies: (1) The clinical outcomes in various studies, measured by Fugl-Meyer assessment (FMA) scores; (2) The fMRI study to measure the functional connectivity and comparison of the connectivity changes before and after the rehabilitation; (3) The structural changes evidenced from DTI image before and after the rehabilitation; (4) The EEG coherence changes as a predictor for BCI based stroke rehab

In summary, we have observed statistically significant clinical outcomes in all three clinical studies comparing the pre- and post-rehabilitation FMA measurements. Functional imaging shows statistically significant enhancement in functional connectivity after training. Initial indication of structural change might imply possible plasticity effects. EEG coherence provides possible prediction for clinical outcome.

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References


Recent studies on ALS and stroke patients are investigating the clinical efficacy of Brain-Machine-Interfaces based interventions. BMIs using electroencephalography (EEG) or electrocorticography (ECoG) in the complete locked in state (CLIS) were largely unsuccessful. No proven case of learning how to communicate with a BMI is documented. We present the first case of a CLIS patient in advanced ALS who learned reliable yes-no communication with a BMI using blood oxygenation levels measured with near infrared spectroscopy (NIRS) after months of random performance with an EEG-BMI. Results interpretations are presented.

Secondly, a controlled-double blind pilot study in chronic stroke patients without residual movement using sensorimotor rhythm (SMR)-EEG-BMI in combination with behavioral physiotherapy demonstrated for the first time that a significant improvement of hand motor function in this treatment resistant population is possible. The experimental group received contingent proprioceptive and visual feedback of SMR-desynchronization with a hand robotic device attached to arm and hand (linking brain and movements), while the control group received random feedback (movements were not linked to brain activity). Both groups received identical physiotherapy. In addition to behavioral improvement, EMG improvement and cortical reorganisation was demonstrated in the experimental group only. We hypothesize that EEG-BMI fails in CLIS while NIRS-BCI works, but EEG-BCI is highly promising in chronic stroke without residual hand movement.

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Recent research in P300 speller Brain Computer Interfaces (BCI) has focused less on P300 detection via improved classifiers and more on developing different speller interfaces and protocols that allow improved accuracy and speed. Research that was led by the ETSU team has demonstrated that the selection of speller layout can improve performance and a layout different from the standard row/column paradigm is often preferred. They have experimented with several other speller parameters in order to optimize the interface for end users, and have tested their paradigms in disabled and nondisabled populations. Recent research led by the Duke team has demonstrated that a Bayesian dynamic stopping criteria where the number of flashes per character spelled is adjusted dynamically can statistically significantly improve accuracy and speed. In this talk we will report on these dynamic stopping results for both disabled and nondisabled populations. In addition, we will present our recent research in which a dictionary-based language model is used in conjunction with the dynamic stopping paradigm to adjust the probabilities associated with the letters being flashed. Results are presented which indicate a statistically significant improvement in speller speed when this probabilistic language model is included. Finally, we will report on our newest results in which the language model is used to perform spelling correction, and also on a study where a clustering approach is used to pre-select from a group of trained classifiers, and demonstrate a dramatic reduction in the amount of time required to train the classifier with little degradation in speller accuracy.

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Over the past 20 years, research on BCIs that can provide communication and control to individuals with severe motor impairment has increased almost exponentially. While considerable effort has been dedicated to offline analysis for improving signal detection and translation, online studies with the target populations are far less common; there remains a great need for translational studies that examine BCI use by target populations. Further, long-term studies with users in the field are required to improve reliability of BCI control. Thus, we are facing a translational and reliability gap. Further research is needed on usability, system robustness and convenience; training and technical support; subject inclusion criteria, recruitment, consent, and retention. The user-centered approach provides a framework to design and evaluate such studies in a standardized way that allows for comparison between different BCI-based applications for communication and control. It includes an iterative process of development and feedback between researchers and users which leads can lead to increasing refinement of the product. Within the user-centered design (1.) usability is defined as effectiveness, efficiency, and satisfaction with regards to the assistive technology device of interest. For BCI-controlled applications effectiveness can be regarded equivalent to accuracy of selections and efficacy to the amount of information transferred per time unit and the effort invested (workload). Satisfaction with a device was assessed for general and BCI specific aspects and included the match between user and technology. Results of first studies with severely motor impaired end-users mostly in their home environment, which implemented the respective evaluation metrics indicated high effectiveness and ITR with P300 based applications for communication and entertainment (2.,3.). While subjective workload was moderate to low, satisfaction was high to moderate. None of the end-users could imagine using BCI for communication, but most could for entertainment even when ITR was low. A high match between user and BCI could be achieved provided the BCI exactly met the individual user’s needs. Using standardized evaluation metrics within the user-centered approach to device development will allow the BCI community to provide BCI-controlled applications for real end-users’ needs in their daily life environment. Thus, the user-centered design appears to be suitable for bridging the translational and reliability gap and ultimately pave the way to independent home use.
S10_5. The Challenge of Communication in Complete Paralysis

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Non-invasive brain-computer interface (BCI) technology allows people to use scalp recorded electroencephalographic activity as a control signal to perform a variety of tasks (e.g., cursor control, word processing, email, environmental control). Because BCI communication does not depend on neuromuscular activity, it can be an effective means of communication for people with severe motor impairments. In most cases, a BCI is the least preferred mode of communication due to functional limitations of these systems, modest rates of accuracy, and low speed – as compared to other augmentative and alternative communication solutions. Nonetheless, a BCI may be the only viable option of restoring independent communication and autonomy for some people who are severely disabled. However, the lack of effective communication makes it difficult, as a researcher, to know if the participant has understood protocols or if the participant has questions, can see clearly, etc. This talk will discuss effective means of overcoming communication barriers and presents work that has improved speed, accuracy, and reliability of BCI systems through systematic paradigm manipulation, as informed by cognitive neuroscience, visual attention, and psychophysiology.

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