Direct Brain Interfaces for Healing Games

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ABSTRACT

Direct Brain Interfaces (DBIs) have been demonstrated to provide a channel of communication and environmental control for people with severe motor disabilities. DBIs have also been proposed and implemented in gaming and other entertainment applications for mainstream users. A new study at Georgia Tech is exploring the possibility of combining direct brain interfaces, gaming, and robotics to pioneer new therapies for stroke rehabilitation for people with residual paralysis or paresis. The aim is to enable a paralyzed patient to operate an upper-limb rehabilitation robot, initially using motor cortical brain signals, in hopes of restoring muscle movement to affected limbs. A simple game environment provides motivation and performance metrics for patients to repeatedly practice targeted reaching tasks. Closed-loop visual and proprioceptive feedback may help restore or replace damaged neural pathways to improve movement ability and stroke recovery.

Author Keywords

Direct Brain Interfaces, Brain Computer Interfaces, stroke rehabilitation, neural plasticity, gaming

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

A *Direct Brain Interface (DBI)* is a system that measures minute changes in brain signals to provide a channel of communication and control that does not depend on muscle activity or limb movement [1]. Direct Brain Interfaces (DBIs) offer great promise as an alternative to traditional input devices to provide assistive technologies for people with severe motor disabilities. DBIs may also have potential as hands-free interfaces or additional channels of control for entertainment and gaming applications for mainstream users. However, combining the two areas of assistive technology and entertainment may catalyze a new and very significant application for DBIs: providing new therapies to restore movement for stroke patients with paralysis or paresis via rehabilitation games.

Recent advances in robotic technology have offered new options for physical rehabilitation of patients with residual muscle activity and limb movement. To date, robot-assisted technology has been successfully applied to restoring locomotion and to rehabilitation of the upper extremity function. However, there are very limited rehabilitation options for stroke survivors with severe paralysis; even rehabilitation robots require slight muscle activity to operate.

Fortunately, new hope may be offered by Direct Brain Interfaces (DBI). DBIs have successfully been used in past studies as communication and control tools for people who have partial or complete paralysis due to stroke or neurological diseases. Building on this research, it follows that combining DBI technology with rehabilitation robotics may provide control paths for rehabilitation for stroke patients suffering from extensive loss of muscle control that might not be possible with existing technologies.

STROKE REHABILITATION

Stroke is one of the leading causes of partial paralysis and long term adult disability in the United States [2,3]. Today, with improved medical treatments, stroke is more likely to result in long term disability rather than death. It is estimated that one in six people over the age of 55 run the risk of suffering a stroke, and currently over 1.1 million Americans over the age of 65 have reported that disabilities from stroke have left them dependent on outside care [2, 3]. With the aging baby boomers increasing the senior population at a disproportionate rate, the concerns of stroke related disability will increase over time.

Robotics for Rehabilitation

Recent advances in robotic technology, specifically, the development of *back-drivable* robots (which are robots that do not resist external perturbations, i.e., they move when pushed) allow for safe interactions between robotic devices and animals or people. This new robotic technology has been demonstrated to have great potential for physical rehabilitation of patients with muscle and neurological diseases or injuries [4, 5]. The advantages offered by the robot-assisted rehabilitation include the ability to assist moving impaired limbs, weight support, precise setting of assistive force or resistance to motion, the ability to quantify the amount/intensity of intervention and monitoring the progress of therapy over time. To date, robot-assisted technology has been successfully applied to restoring locomotion and to rehabilitation of upper extremity function.

Restoring Upper Extremity Function after Neurological Trauma

Several research groups have examined the efficacy of robotic-assisted exercise as an intervention to improve upper extremity function in patients with neurological disorders, particularly stroke [4-7]. In the current health care environment, robotic-based therapies require less direct supervision and result in improved outcome. Robotic devices currently studied in clinical trials include the MIT-Manus, which is a two-joint manipulandum [8] and the exoskeleton robotic arm and hand design used in treating a variety of neurological disorders [9,10]. These studies have shown that stoke patients with moderate upper limb impairment were able to improve in functionality of the impaired arm faster compared to traditional therapy.. Preliminary results of robot-assisted rehabilitation in stroke patients suggest several important conclusions: (1) movement training (training movement coordination) is more important than training muscle strength; (2) passive patient movement is insufficient for improvement; (3) active participation of the patient is required to achieve progress [11].

The robotic device we are using in this study is the KINARM^{TM} upper-limb rehabilitation robot, developed and sold by BKIN Technologies, OT, Canada shown in Figure 1, which allows and supports movement in two dimensions. The subject moves their arm in a horizontal plane, possibly with the support of the robot. The robot also has a projection capability onto a horizontal surface for displaying targets for movement and reaching tasks.

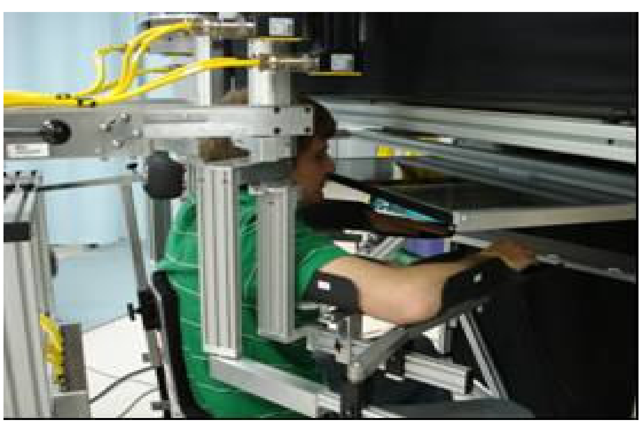

Figure 1. A subject performing reaching tasks using the KINARM^{TM} robotic device in the Biomechanics and Motor Control Lab at Georgia Tech (Dr. Boris Prilutsky, director).

DIRECT BRAIN INTERFACE CONTROL OF MOTOR TASKS

One of the approaches to DBI control studied by the GT Brainlab involves focusing on hand and limb movement to evoke changes in a brain signal called the *mu* sensorimotor rhythm, an 8-12Hz signal that subjects can learn to amplify or attenuate with mental imagery or actual motor activity [12-15]. In several cases, after training, paralyzed subjects have shown increased motor ability in parts of the body on which they were asked to focus their attention [16-18]. While these observations are anecdotal, from these observations we speculate that the mental activity involved in operating a DBI may promote neural reorganization similar to that which occurs when adding intention-based tasks to motor practice [17, 18, 20, 21]. From these observations and from the results of the studies mentioned above, a compelling question arises: can DBI technology be incorporated into robotic rehabilitation to improve movement-restoration therapies? Restoring mobility could provide significant benefit to people with severe motor disabilities caused by stroke and other neurological conditions.

The primary goal of our research is to determine the potential of applying DBIs to robotic rehabilitation, to influence *neuroplasticity*, which refers to changes in the organization of the brain in response to experience. Robotic rehabilitation and DBI applied independently to rehabilitate patients with neurological disorders cause certain plastic changes in the brain resulting in improved motor performance [4,5,7,19]. It may be possible to accelerate rehabilitation and plastic changes in the brain by the simultaneous use of the two approaches. The motivation behind this goal is to find a method of motor rehabilitation that can benefit patients who have little or no residual motor ability in a limb. Our research couples two major rehabilitation paradigms that have been demonstrated to effectively influence neuroplasticity: active motor training through the use of a robot [5, 19-21] and mental imagery through the DBI control system [17-20]. The DBI adds the benefit of producing a closed loop system, similar to normal motor control. This system allows the subject to indirectly control movement and receive the visual and proprioceptive feedback necessary for motor control and training.

Previous work in motor cortex

The GT BrainLab has conducted extensive studies of motor cortical rhythms for control of assistive technology such as communication and environmental control applications. Working with the Wadsworth Center, The BrainLab implemented neural control for a robotic arm moving in two dimensions. The movement of the robot was measured by a targeting display and acquisition system. Results from the Wadsworth study include algorithms for navigating in two dimensions and measurements of the speed and accuracy with which physical devices can be controlled by brain signals [22].

HEALING GAMES

The overall goal of this research is to determine if a Direct Brain Interface can be successfully integrated with a rehabilitation robot to provide therapeutic options for people with severe motor disabilities. However, to make the sometimes tedious and repetitive movements of stroke rehabilitation therapy more engaging, we are incorporating reaching movements into simple games requiring target acquisition. The initial game for the study is patterned after the legendary "Pong" of early gaming devices. A "ball" or cursor appears from one side of the display area, moving at a constant speed horizontally. The subject performs a targeted reaching task moving a "paddle" to intercept the path of the "ball". If intercepted, the "ball" bounces back and then is presented to the subject again on a different trajectory. The trajectory of the "ball" can be controlled to require the subject to move to various target locations needed in the therapy protocol. The speed and size of the "ball" and "paddle" can be altered to increase or decrease the difficulty of the reaching task. Performance metrics in the game as well as data collected by the robotic arm can track subjects' progress.

In order for subjects who have severe paralysis to control the reaching task without needing muscle movement, we employ a mu-based (EEG) DBI. The DBI will, at least initially, move the subjects' arm with motor imagery alone. In order to create brain signal classifiers that can recognize movement patterns for this type of target acquisition, we are currently gathering repository data on EEG signals produced by able-bodied subjects performing simple and complex upper limb reaching tasks. We observe the activity present in the motor cortex region correlated with task performance. The results of analyzing the EEG signal patterns will be used to refine existing signal processing algorithms for controlling a rehabilitation robot using DBI.

Our next step is to conduct a study with able-bodied subjects who will learn to control the robot during the Pong game with imagined movement only. Subjects will keep limbs still; there will be no motion-dependent proprioceptive feedback, only visual feedback. Task performance data will determine the effectiveness of control. We will perform feature-based analyses of EEG activity of the subjects before and after DBI training to calculate whether there appears to be a distinct component in the EEG that is uniquely influenced by DBI training and we will contrast the rate of motor adaptation and reaching accuracy of the subjects.

The last component of this study is to work with stroke patients, applying the improved classifiers to implement control of the Pong game with imagined movements. Changes in the subjects' movement abilities will be measured and analyzed to determine if the addition of the DBI to the robot enhances rehabilitation therapy.

CONCLUSION

The millions of people currently suffering from severe or complete paralysis from stroke or other brain injuries could benefit significantly from the progression of this research. DBIs offer a communication pathway from the brain that opens possibilities for people whose disabilities are so severe that they are not able to respond to traditional rehabilitative treatment. With this research, we hope to advance the state of the art in brain signal pattern recognition and rehabilitation robotics, and to enhance understanding of neural organization and plasticity in motor cortex. Results from this work may also apply to control of prosthetics and other assistive technologies for people with paralyzed or amputated limbs.

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