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A STUDY ON THE PERFORMANCE OF VARIOUS BRAIN-COMPUTER INTERFACES

Aarathi Kumar[1], Nisha. P. V[2]

[1]PG Scholar, [2]Asst. Professor, ECE, Kerala University, (India)

ABSTRACT

Brain-Computer Interface (BCI) is a mechanism that helps in the control/communication of one's environment through the brain signals obtained directly from the brain via an EEG signal acquisition unit. This avoids the dependency on the normal neuro-muscular pathway in the CNS and increases the recovery of damaged brain cortex through neuroplasticity. A survey of various BCIs designed is discussed in this paper. Finally a BCI incorporating Motor Imagery is designed which aids the fully disabled patients in the rehabilitation of upper limbs. It helps in restoring some of the activities of the daily living. It aids post-stroke sufferers to carry out functionalities like movement of right and left hands, grabbing things, twirling etc.

***Keywords:* Brain Computer Interface, CNS, EEG, Motor Imagery, Neuroplasticity.**

I. INTRODUCTION

The dream of being able to control one's environment through thoughts had been in the hands of fictional films. However, the advanced technology has brought it into new reality: Nowadays, humans use the electrical signals from brain activity to communicate with, influence, control, or change their environments. The emerging brain-computer interface (BCI) technology allows individuals who are unable to speak and/or use their limbs to communicate or operate or control devices like robotic arms, wheel chairs for walking and manipulating objects. Brain-computer interface research is an area of high public awareness. It improves the lives of many disabled persons affected by a number of different disease processes.

This excitement reflects the rich promise of BCIs. They can be used routinely to replace or restore useful functions like moving arms, legs or communicating with the environment etc for people severely disabled by neuromuscular disorders; they can improve rehabilitation by influencing the brain directly for people with strokes, epilepsy, head trauma, and other disorders.

The development of BCIs for people with disabilities requires clear accuracy and validation of their real-life value in terms of efficacy, practicality and impact on quality of life. This depends on researchers who are able and willing to undertake research for finding the real-life use in complicated and often difficult environments like gestures, movements, speech etc. Such studies, which are just beginning, are an essential step if BCIs are to realize their promise.

II. EXISTING METHODS

At the present scenario, the achievements of BCI research and development remain confined almost entirely to the laboratory, and the major work to date comprises data gathered from able-bodied humans or animals. Studies in the ultimate target population of people with severe disabilities have been largely confined to a few limited trials closely overseen by researchers. The conversion of the exciting laboratory progress to clinical use, to BCI systems that actually improve the activities of the daily lives of people with physical disabilities, has barely begun. This essential task is perhaps more demanding than the research that produces a competent BCI system. It must show that a specific BCI system can be implemented in for long-term training use without the aid of therapists, define the appropriate user population, and establish that the BCI improves their standard of living.

These systems use different brain signals, recording methods, feature extraction and classification algorithms. They can operate many different assistive devices like cursors on computer screens, wheelchairs, robotic arms etc. Better signal-acquisition hardware, more specific algorithms, clear clinical validation and increased reliability, BCIs may become a major new communication and control technology for people with disabilities.

A. Upper Limbs Rehabilitation Using Motor Function Training Assisted System[16]

Task-oriented motor function training and assistance of upper limbs system after brain injured such as stroke based on Virtual-Reality had been designed in 2009. In this system, two kinds of training approaches are developed - One is tracking training with path-unlimited based on a mass-spring-damper force model, and other is tracking training with path-limited based on a compound force model. Both of training approaches are same that coordination motion of two hands is needed. Further, the effect of system is enhanced through adding assistance in order to help mild stroke patients to recovery. This system is convenient and compact so that it is suitable for home-based rehabilitation.

The most significant physical impact on stroke survivors is long term disability. In the stroke survivor population, 50% have some level of hemi- paresis. These stroke patients needed locally based multi-disciplinary assessments and appropriate rehabilitative treatments after they were dismissed from hospital. The conventional rehabilitation for stroke patients which relies on the use of physiotherapy and the therapists training and experience is called passive rehabilitation. Meanwhile there is another method called active rehabilitation that patients can restore their motor function through using certain system by them. This method is mainly used in home-rehabilitation.

The benefit of coordinated interdisciplinary stroke care has been shown to reduce mortality, reduce the percentage of patients requiring institutionalization and reduce dependency in mobility and self-care skills. With the development of robotics technology, robot-assisted systems for physical and neurological rehabilitation for patients who have suffered physical or neurological injuries have been developed. They are also candidates as tools in other neurological conditions characterized by motor deficits, such as multiple sclerosis or spinal cord injury, as well as for training healthy subjects to perform skilful movements, such as those required for surgery, writing, or athletics Recently, execution-observation system called Mirror Neurons. Tools in other neurological conditions characterized by motor deficits, such as multiple sclerosis or spinal cord injury, as well as for training healthy subjects to perform skilful movements, such as those required for surgery, writing, or athletics.

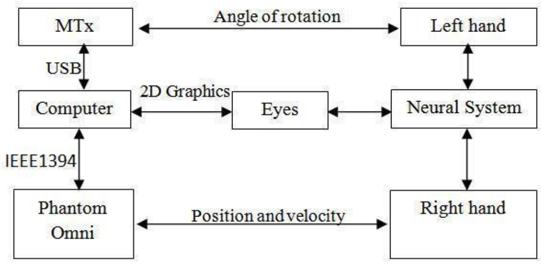

Fig.2.1. The schematic diagram of the system

Recently, an execution-observation system called Mirror Neurons has been found and it has been proved that action observation may also induce cortical plasticity. Maybe observation stimulates patient's cognitive processing and strengthens patient's recovery. The ability of motor function of patients can be improved through doing some training which needs strength and dexterity. The system is designed to be manipulated with two hands, which one hand is impaired and the other hand is intact, moreover, the intact hand can supply assistance to the impaired hand. In order to absorb subjects' attention, subjects should coordinate the motion of their two hands to track a moving virtual object randomly.

B. Robotic, VR and High Resolution EEG Imaging in BCI[7]

A system for the neuro-motor rehabilitation of upper limbs in stroke survivors was proposed in 2013. The system is composed of a passive robotic device (Trackhold) for kinematic tracking and gravity compensation, five dedicated virtual reality (VR) applications for training of distinct movement patterns, and high resolution EEG for synchronous monitoring of cortical activity. In contrast to active devices, the Trackhold omits actuators for increased patient safety and acceptance levels, and for reduced complexity and costs. VR applications present all relevant information for task execution as easy-to-understand graphics that do not need any written or verbal instructions. High-resolution electroencephalography (HR-EEG) is synchronized with kinematic data acquisition, allowing for the epoching of EEG signals on the basis of movement-related temporal events. Neurological injury after stroke frequently leads to hemiparesis or partial paralysis and, despite labor-intensive conventional rehabilitation therapies, more than half of stroke survivors report disability in at least one activity of daily living (ADL). Robotic-based systems have the important advantages of allowing for real-time limb position and force measurement, for programmable movement patterns and precise control of movement repetitions. To avoid early fatigue, robotic-based systems can support the patient passively by gravity compensation and/or actively through electric or pneumatic actuators that assist the patient during movement execution. The drawback of active robotic devices is that they tend to be rather complex and expensive, and actuators may present a risk factor for patient safety. Indeed, in the remote case of system failure, the patient's limb might be moved with unexpected high force or speed. Counter-measures can be taken via software by reducing the maximum force/speed under safe thresholds, and/or via hardware by mechanically limiting the system's range-of-movement. However, software constrains can make the haptic interaction too weak for an effective rehabilitation of the whole arm, whereas a mechanical reduction of the workspace might result in a non-optimal rehabilitation outcome. Differently from robotic devices, consumer electronics-based systems do not directly apply any force to the patient's limb and therefore are not liable to the same kind of potential risks. Instead, the patient interacts with a virtual reality (VR) environment suitable for visual task presentation and biofeedback either via a video game controller or contactless via a video camera.

The two major features commonly employed in all VR training applications are the workspace scaling and translation. Patients' movements outside the configured effective workspace are not obstructed by actuators or by mechanical means, because the Trackhold is a passive robotic device. As long as the end-effector remains outside the effective workspace, its trajectories are still recorded for data analysis purposes. On the other hand, workspace translation allows shifting the centre of the effective workspace relative to the patient's upper body in order to adapt to his/her body height, arm length, etc., error handling, and output on subject's monitor. The VR training applications simulate ADLs and/or reproduce simple visuo-motor coordination tasks. Subjects interact online with the VR training applications by moving the Trackhold's end-effector, and observe the changes occurring in the VEs in real time on a 22-in LCD monitor placed in front of them at eye-level at a distance of 90 cm. Subjects have to follow trajectories in varying workspaces, depending on the specific application. In order to permit repetitions of the same task with minor alterations (e.g., reaching towards randomly varying target positions), the movements necessary to perform the tasks are short in time. In order to avoid fatigue, the subjects are instructed to return their arm to the neutral position during the inter-trial resting periods. Intuitive graphical representations are used to visualize the information relevant to the subject for controlling his/her movements, such as the current positions of the hand and the target.

C. EEG based BCI for Post-Stroke Motor Rehabilitation of the Upper Limb[12]

Brain-Computer Interfaces (BCIs) process brain activity in real time, and mediate non-muscular interaction between and individual and the environment. Specific algorithms can be used to provide a quantitative measurement of physiological or pathological cognitive processes – such as Motor Imagery (MI) – and feed it back the user. In this paper, the clinical application of a BCI based rehabilitation device, to promote motor recovery after stroke is proposed. The BCI-based device and the therapy exploiting its use provides the physical therapist with a monitoring instrument, to assess the patient's participation in the rehabilitative cognitive exercise; assists the patient in the practice of MI. The device was installed in the ward of a rehabilitation hospital and a group of 29 patients were involved in its testing. Among them, eight have already undergone one month training with the device, as an add-on to the regular therapy. The rehabilitation exercise based on BCI mediated neuro feedback mechanisms enables a better engagement of motor areas with respect to motor imagery alone and thus it can promote neuroplasticity in brain regions affected by a cerebrovascular accident. Preliminary results also suggest that the functional outcome of motor rehabilitation may be improved by the use of the proposed device. Brain-Computer Interfaces (BCIs) collect the physical correlates of the brain activity (e.g. the Electroencephalogram, EEG), and process them in real time, with the aim of executing actions on the users environment and/or providing the user with a feedback of specific processes occurring in the brain. Classically, BCIs have been targeted to the restoration of communication functions in individuals with severe motor disabilities, or more generally their ability to interact with the environment. Since BCI is based on the detection of the occurrence of physiological or pathological brain activity, it can be used to provide a quantitative measure of such cognitive processes, which can be fed to a therapist, or back to the user. One of the most recent and promising application fields of the BCI technology targets motor rehabilitation of stroke patients. In fact, the practice of motor imagery (MI) has been suggested to improve motor recovery after stroke, by inducing use-dependent plastic changes in the lesioned hemisphere. In this respect, EEG-based BCI systems operated via MI appear to be a promising option to promote restoration of motor function after stroke, by exploiting the neuroplasticity phenomena induced on the motor cortex by the BCI training. In an effort to deploy a practical EEG-based BCI system as an effective post stroke rehabilitation training tool, it is crucial to define which EEG patterns (sensorimotor rhythms, SMR) are expected to correlate with desirable neuroplasticity and thus reinforced through the BCI training. Moreover, to effectively encourage training and practice the BCI design should incorporate principles of current rehabilitative settings, suitable to stimulate patients' engagement during the exercise. The ultimate goal is to let the patients re-learn their motor scheme by having voluntary (covert and/or overt) access to the affected limb.

D. Computer games for post-stroke arm tele-rehabilitation[13]

Research shows that better results in rehabilitation are obtained when patients receive more intensive therapy. However this intensive therapy is currently too expensive to be provided by the public health system, and at home few patients perform the repetitive exercises recommended by their therapists. Computer games can provide an affordable, enjoyable, and effective way to intensify treatment, while keeping the patient as well as their therapists informed about their progress. This paper presents the study, design, implementation and user-testing of a set of computer games for at home assessment and training of upper limb motor impairment after stroke. Few patients regularly perform the typically boring and repetitive exercises recommended by their therapists. Moreover, neither the quality nor quantity of training performed can be objectively tracked. Computer games can provide an enjoyable and effective way to motivate patients to increase both the quality and quantity of therapy at home by decreasing the monotony of performing hundreds of repeated motions and by providing challenging performance feedback. In addition, games can also be used to remotely assess the motor impairment of patients without the need for the therapist to be present. Therefore, together with cheaper robotic solutions for training at home, computer games represent an affordable way to both facilitate the patient access to rehabilitation and reduce the strain on the healthcare system. This paper presents the design and implementation of 4 games for assessment and 4 games for training of post-stroke arm motor impairment to be used with the Arm Assist device together with the Tele-Reha web platform for at-home tele-rehabilitation. Arm assist assists the horizontal movement of the arm by supporting its weight while measuring the movement parameters (2D position, orientation and arm support/lifting force) that are used to control the games. The training can be continued at home without the need of therapist / hospital equipment.

III. METHODOLOGY

Objective of this paper is to design a BCI to help completely bed-ridden patients who have no mobility to carry out their activities of daily living. After completion of this work, patients will be able to restore some of the activities of daily living. This is achieved by using a Brain-Computer Interface (BCI) with an effective visual feedback to the user so that the output devices like robotic arms, wheelchairs, computer cursors etc can be moved with more accuracy.

Post stroke patients or patients with neuro-muscular disorders like stroke can be trained using this BCI so that it helps to restore the damaged cortical areas. It also encourages neuroplasticity in humans so that much functionality of the human beings can be restored. The training therapy can be carried out by the patients themselves so that there is no necessity of a physical therapist. Hence the therapy can be continued at home, i.e.;

home based rehabilitation will be possible. This leads to continuous training process to be carried out, increasing the efficiency of the whole system.

The main objective includes the rehabilitation of both the upper and lower extremities-it can be extended to both the upper limbs and the knee of post-stroke sufferers wherein the knee rehabilitation is carried out at an early stage of stroke while upper limb rehabilitation can be extended to later stages of therapy.

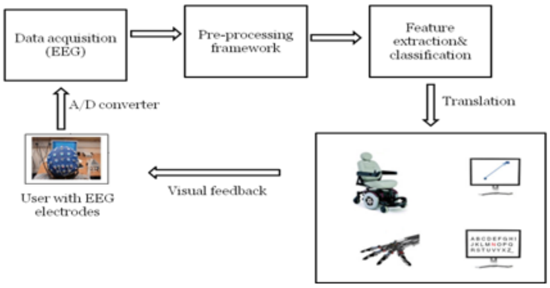

Fig.3.1. The schematic diagram of the system

Throughout this paper, the various steps of the methodology will be optimized and the most appropriate steps will be followed to achieve the objectives of this work. The level of optimization is high in the feature extraction and classification steps wherein various classifiers can be used to satisfy the current applications. The primary phenomena observable during motor imagery is the event-related desynchronization (ERD), caused by the blocking in and frequency ranges during the imagery event, and the event-related synchronization(ERS), caused by the posterior unblocking of frequencies. The ERD/ERS phenomena have different spatial characteristics for each observable event. Left hand imagery causes ERD in the right contra-lateral area of the sensorimotor cortex while right hand imagery happens in the left area. Knowing that these events occur in the μ and β ranges, it can be band passed using a bank of filters and then enhance the signal-to-noise ratio of the events of interest by using the common spatial patterns (CSP) algorithm. For filtering, use seven band-pass zero-phase Butterworth filters with central frequencies spaced between 8 and 30, with a Q factor of 1.33 and order 4. It is followed by applying CSP to each one of these filters outputs. CSP is a data-driven technique to analyze multi-channel data recorded from two classes.

IV. RESULTS AND CONCLUSION

Brain-computer interfaces allow the Central Nervous System (CNS) to acquire neuroplasticity and new skills in which brain signals/ electrical signals directly from the brain take the place of the normal spinal motor neurons that produce normal neuro-muscular path. Neuroplasticity is a mechanism that requires practice over months and enables babies to walk or talk; children to learn reading and writing; and adults to acquire athletic movement and intellectual powers. The acquisition and maintenance of BCI-based on skills like communication, reliable multidimensional movement control requires comparable plasticity. The BCI should be adaptable to the environment so that its outputs correspond to the user's imagined movement or desired intent. Same time, the BCI should encourage and facilitate CNS neuroplasticity that improves the precision, accuracy and reliability with which the brain signals encode the user's desired action. In sum, the BCI and CNS must work together to acquire with accuracy and maintain a comparatively reliable partnership under all circumstances.

The principles underlying how the CNS acquires, improves, and maintains its normal muscle-based actions may be the best guide for designing BCIs. CNS control of motor actions is normally found across multiple cortical areas across the brain. Patch-cortical areas of brain define the goal of an action; however, the details of how the cortex fires electromagnetic field are often handled at lower levels.

Brain-computer interface performance is highly benefited from distributed control across the electrodes placed according to 10-20 standards. For BCIs, the distribution would be between the BCI's output control signals and the application device that receives the commands from the control signals and converts them into action by translation algorithms. The optimized distribution of the signals will vary from BCI to BCI, from person to person and from task to task. Realization of suitable and reliable BCI performance may be accomplished by incorporating into the application itself as much control signals as is reliable or consistent with the action to be produced, just as the normal neuromuscular action. The normal neuro-muscular outputs reflect the combined contributions of many brain cortical areas to the spinal cord. BCI performance can be improved and maintained by using signals from multiple brain cortical areas like sensory motor area, visually evoked area etc and by using brain signal features that reflect relationships among these cortical areas (eg, coherences). This approach could improve BCI reliability to a greater extent.

The use of signals from multiple cortical areas might also resolve another obstacle to implement fully practical BCIs. In current BCIs, the therapists rather than the user typically determine when output is produced. Ideally, BCIs should be controlled by the patient himself or should be self-paced, so that the BCI is always available according to the desire of the user and the user's brain signals alone control the BCI and determines when BCI output is produced. Brain-computer interfaces that use signals from multiple cortical areas of the brain are more likely to be sensitive to the current context and thus may be better able to assume or recognize when their output is or is not appropriate for the current situation.

The field of BCI research and development has focused primarily on rehabilitation of post-stroke patients or neuroprosthetics applications that aim at restoring damaged hearing, sight and movement.

V. COMPARISON

The previous works focused on the neuro - motor rehabilitation of patients taking input for the BCI from a therapist. The main disadvantages included Muscle Fatigue, High Cost, Safety Issues, patients need to have some type of movement and no Home-Based Rehabilitation was possible. The idea of the novel approach is to use Enhanced Feedback using steady state visually evoked potentials and motor imagery to help patient who are completely bed-driven to communicate with the environment via devices like robotic arms. It also helps in the restoration of some of the damaged cortical areas in the brain of the patient. Further rehabilitation is provided for both the upper limbs and knee as opposed to the previous work where only the upper limb rehabilitation was considered. The training can be continued at home without the need of therapist / hospital equipment. Active participation of the patients is guaranteed as there is no muscle fatigue and whole set up is user-friendly and safe to handle.

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