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Overview

Interface providers in stroke neurorehabilitation

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Abstract

Every year, 15 million people worldwide suffer a stroke, when the blood supply to the brain is blocked or when a blood vessel in the brain bursts. After a stroke, specific pattern of cortical reorganization has been described (1). During the past few years, three principles for remodeling motor cortex; forced use of the affected limb (2, 3,), constraining the unaffected limb (5), and massed practice (6), showed very promising results (7, 8, 9, 10)

But the question remains: What's the most effective way to reach restoration of the whole body movement?

Advances in clinical neurology, embodied cognitive neuroscience and computer technology have made possible the emergence of a new set of neurorehabilitation tools, helping physiatrists and neurologist to find evidence-based answers in the form of clinical trials. Interface here are define as a point of interaction helping communication between the patient and his own body, using feedback and feedforward signals.

INTRODUCTION

The usual concept of brain computer interface is the development of new technologies enable to transform thoughts of the patient in movement of a neuroprosthetic arm, wheelchair or robotic device.The aim of our review is to generalized the concept of interface, defining it as any point of interaction between the patient's conscious self and various internal and external means used to make patient fully aware of his current position, here in a stroke recovery process.

We propose a time based classification in order to separate new computer technologies, able to offer real-time feedback, from interfaces depending of the ability of the patient (and/or his caregiver) to keep a recovery diary, and the ability of the physician to define with the patient a recovery plan, guide him through recovery process, and provide quality clinical assessment scales.

The development of a new field of neurorehabilitation devices acting as short-term, almost real time interface providers is emerging. The concept is to provide feedback and feedforward signals to the patient's brain depending of brain waves frequencies (Electroencephalogram or EEG neurofeedback), patient movement (motion tracking feedback, virtual reality and control balance system), physical property of the surrounding space (sensory substitution) or electrical activity of smaller and smaller amount of neurons (neuroprosthetics and brain computer interface in the original sense of the term).

We define recovery diary as a medium-term interface provider with a time window from each day to each week. The input is the patient himself with the help of his caregiver, and it represent a strong tool for recovery.

Stroke physicians are define as long term interface providers since the patient see them after leaving the hospital each one, three or six month. The verbal input from the physician remains one of the most important variable for stroke recovery.

A. Short-term feedback interfaces

1. EEG NEUROFEEDBACK

Electroencephalogram (EEG) is produced by synchronous postsynaptic potentials

from cortical neurons, recorded at the scalp. The raw EEG signal is amplified, digitized, plotted, and filtered to isolate narrow frequency bands (defined in Hz) that reflect specific brain sources and functions (*10*).

EEG neurofeedback refer to the conversion of information on brainwave activity (quantitatively measurement of brainwave frequencies) into graphe-like or game-like displays *(11)*. When the patient learns to control and improve brainwave patterns, the game scores increase and progress occurs.

Until now, most frequent application areas include Attention Deficit Disorder *(12, 13),* Anxiety-Depression spectrum *(14)* and seizures *(15)*.

In a pilot study in which an EEG-based Brain computer interface system was used to provide neurofeedback to stroke participants during mental practice helps patients to undertake it with stronger focus, leading to better outcomes *(16)*.

2. EMG BIOFEEDBACK

This biofeedback setup uses an EMG sensor to represent muscle tension as a series of beeps and allows the patient to train his body to adjust muscle tension at will. In short, the more tense the muscles are, the faster the beeps become, and the more relaxed, the slower. The use of electromyographic biofeedback is not new in neurorehabilitation *(17, 18)*. This involves the use of instrumentation applied to muscles with external electrodes to capture motor unit electrical potentials, in order to convert these potentials into auditory or visual information. In 2006, a Cochrane review assessed the effects of EMG-Biofeedback for motor function recovery following stroke. Only one study used a motor strength assessment scale for evaluation of patients, which indicated benefit from EMG-BFB, but further well-designed protocols have to be devised and applied *(19)*.

3. MIRROR VISUAL FEEDBACK

One way to „fool" the brain by inducing a conflict between proprioception and vision is to use a vertical mirror positioned sagittally in the middle of a box in which the patient places his paralyzed hand on one side of the mirror and the normal hand on the other. When the patient looks in the mirror, the mirror reflection of normal hand is superimposed on the image of the paralyzed hand.

Such mirror box was first used by Ramachandran for amputees with phantom limb pain *(20),* and subsequently in a pilot study of stroke survivors *(21)*. Recently, two randomized-controlled trials of mirror therapy have found significant improvement from hemiparesis *(22, 23)*. The conflict induced between vision and proprioceptive feedback seems to rewire the premotor cortex by activation of the right prefrontal cortex. The illusion of movement seems to be the best way to rewire the part of the brain where the movement was encoded *(24)*

4. MOTION TRACKING FEEDBACK

Motion tracking feedback devices in motor neurorehabilitation use the fact that task oriented action execution combined with the observation of virtual limbs that mirror the executed or intended movement enhances functional reorganization of the motor and pre-motor cortex affected by stroke.

Motion tracking feedback tracks limbs movements and maps them onto a virtual environment.

The user controls the movements of two or four virtual limbs that are viewed in a first person *(25, 26)* or third person perspective *(27)* on a screen.

5. VIRTUAL REALITY

Virtual reality typically refers to the use of interactive simulations created with computer hardware and software to present users with opportunities to engage in environments that appear and feel similar to real world objects and events *(28, 29)*.

Virtual reality is a computer based, interactive, multisensory simulation environment that occurs in real time. Several Virtual reality systems have been proposed for the rehabilitation of motor deficits following stroke with particular emphasis on the rehabilitation of the upper limb and the hand *(30, 31)*. Some virtual reality based stroke rehabilitation systems are coupled with physiological measurements, like heart rate and skin conductance, because specific events that occur during the exercise and the general difficulty of the exercise can affect various physiological indicators of the patient's arousal *(32)*. This approach could facilitate real-time adaptation of the game parameters in order to maintain patient's arousal and performance at a desirable level.

In 2011, a Cochrane review included 19 trials which involved 565 participants. Authors found limited evidence that the use of virtual reality and interactive video games may be beneficial in improving arm function and ADL function when compared with the same amount of conventional therapy, but there was insufficient evidence to reach conclusions about the effect of virtual reality and interactive video gaming on grip strength or gait speed *(33)*.

6. BALANCE CONTROL SYSTEM

During postural stability, the nervous system controls muscles by activating flexible combinations of muscle synergies to produce movements. activity of muscle synergies can be correlated to functional outputs related to task performance *(34)*.

Feedforward neuromechanical elements are here those that adjust the intrinsic mechanical stability of the musculoskeletal system in anticipation of a postural perturbation(postural configuration and postural muscle tone), and Feedback neuromechanical elements are those that activate muscles reactively following postural perturbations, and include task-level feedback gains, muscle synergies, and spinal reflexes *(35)*.

New technologies combining visual, proprioceptive and vestibular feedback machines are emerging: the patient receives visual information about his postural control and contraction strength during rotation of a motorised platform. The aim is to combine and add reliable feedforward and feedback element in order to adapt movement execution and coordination through statistical learning processes *(36)*.

7. SENSORY SUBSTITUTION

Paul Bach-y-Rita argued that persons who become blind do not loose the capacity to see. Usually, they loose the peripheral sensory system (the retina), but retain central visual mechanisms. Based on this principle, he developed the field of sensory substitution using human machine interface *(37, 38)*. The principle is that information from an artificial receptor is coupled to the brain via a human–machine interface. Sensory substitution can occur across sensory systems, such as touch-to-sight, or within a sensory system such as touch-to-touch.

Many studies have demonstrated that comparable subjective images are experienced by blind persons using one of several sensory substitution systems *(39, 40)*. For example, in auditory-vision sensory substitution, a system couples a rough model of the human retina with an inverse model of the cochlea, using a pixel-frequency relationship. A head-mounted TV camera allows on-line translation of visual patterns into sounds *(41)*.

The challenge for future investigation will be to find which sensory system in which patient will be the most appropriate for neural substitution mechanism.

8. EEG CONTROL SYSTEM NEUROPROSTHETICS

To capture electrical signals from the brain, the vaste majority of subspecialized centers are using microelectrodes implanted in the skull to record electrical activity, transducing recorded information through a thin cable in order to decode neuronal signals and output them to computer cursors, robotic limbs or exoskeletons that patients can control by thinking about movement.

However, a team from the bioengineering department of the University of Maryland showed that it is possible to capture and decode three-dimensional hand motions from the amplitude modulations of the smoothed EEG signals in the lower frequency delta band (<4 Hz) emanating from the scalp. their results were comparable to almost any invasive method *(42, 43)*.

B. Medium-term feedback interface: the recovery plan

Define a recovery plan as a medium term feedback interface has for aim to enhances the fact that patient himself and his motivation for recovery is the crucial factor for rehabilitation.

By recording his recovery process, via a daily-based diary, the patient can follow his own results during the process of rehabilitation.

The patient who accurately record his rehabilitation will be far more aware of his progress. Recovery diary can be record by writing, audio/video tapes, etc.

Before recording a diary, it is extremely useful to set up a recovery plan.The elaboration of the plan begins in the hospital, right after the stroke or brain injury, and it continues to develop during time involved in home therapy, skilled nursing facilities, rehabilitation hospitals or outpatient clinics *(44)*.

The recovery plan has to meet some important criteria and has to be:

Specific: The benefit come from working on the exact skill the patient is interested in, for example personal hygiene, compose telephone number, etc. Every repetitive task has to be task-specific.

Measurable: Measuring walking distance, saying a sentence, everything can be timed and measured by audio-and videotaping.

Attainable: Keeping goals that patient work towards small and achievable, the recovery plan must be flexible and realistic. It is important to record performance goals more that outcome goals and take account of the environment of the patient, as business strategy must predict unexpected effects of government policy, and sport goals must take into account possibility of poor judging, bad weather or injury.

Timely: Goals have to be write down in order to range them in dates, times and amounts so that we can measure achievement after a defined period.

C. Long-term feedback interface: reliable clinical scales and communication skills of the therapist

The wide accessibility of information about diseases transformed deeply the relation between patient and his therapeut. Patients are well-informed about their diseases, prognostic and therapy. We argue that the role of physician became to guide the patient through his disease in order to explain what the patient can expect during his recovery process, One way is for example to explain him Brunnstorm's stages of recovery *(45)*.

Here we considere the physician/therapeut as an interface, as a point of interaction between patient and his disease, helping to enhance communication between the patient, his body and his mental processes.

Some vitals skills required in communication with patients are:

a) The ability to listen to patients, ask for and respect their views about their health, responding to their concerns and preferences

b) The ability to share the information they want or need to know about their condition and its likely progression

As the aim is to make patient fully aware of his current position in the recovery process, recovery is to be a patient drive.The objectives to attain are patient satisfaction and patient enablement, through patient empowerment. Physicians who empower their patients maintain the belief that people have the capacity for change and are equipped with the inner resources to do so, even if they never do change.

In order to fulfill the lack of evidence-based data for the wide amount of neurorehabilitation devices, scientific, medical and technological communities should intensively cooperate on this emerging field.

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