Neuronal plasticity mechanisms induced by brain-machine interfaces: connecting brain to artificial neural network

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Abstract

Brain-machine interfaces, also known as Brain-Computer Interfaces (BCI), are devices that connect the brain to a computer. In the last decade it is been used to investigate the restore of sensorimotor function in patients with cortical damage. Some evidence supports that the results obtained in the research using BCIs in the treatment of these patients are directly dependent on plasticity mechanisms very similar to those observed in learning and memory tasks. Recent studies have been making use of Artificial Neural Networks (ANN) to classify signal patterns throughout neuronal circuits in order to command movements. In this review, we attempted to make a survey on the available data in the literature on this topic in order to gather the most relevant evidence of such mechanisms and the role of ANN on human brain neuronal input decoding compared to other data processing techniques.

Keywords: *Artificial Neuronal Networks, Brain-Machine interface, Learning, Motor Cortex, Neuronal plasticity.*

Resumo

As interfaces cérebro-máquina, também conhecidas como Brain-Computer Interfaces (BCI), são dispositivos que conectam o cérebro a um computador. Na última década tem sido utilizado para investigar a restauração da função sensório-motora em pacientes com lesão cortical. Algumas evidências apóiam que os resultados obtidos na pesquisa utilizando BCIs no tratamento desses pacientes são diretamente dependentes de mecanismos de plasticidade muito semelhantes aos observados nas tarefas de aprendizagem e memória. Estudos recentes têm vindo a fazer uso de Redes Neurais Artificiais (RNA) para classificar padrões de sinal em circuitos neuronais, a fim de comandos movimentos. Nesta revisão, tentamos fazer um levantamento sobre os dados disponíveis na literatura sobre este tópico, a fim de reunir a evidência mais relevante de tais mecanismos e o

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papel da RNA sobre o cérebro humano neuronal entrada decodificação em comparação com outras técnicas de processamento de dados.

Palavras-chave - *Redes Neuronais Artificiais, Interface Cérebro-Máquina, Aprendizagem, Cortex Motor, Plasticidade Neuronal.*

INTRODUCTION

Brain-computer interface (BCI) is the device that connect the brain to machines in order to restore sensorimotor functions in compromised patients [1,2]. Neuronal plasticity is related to the capacity of reorganization of neuronal circuits, by processes ranging from learning to repair of neuronal damage [3,4].

There is evidence suggesting that neuronal plasticity is one of the mechanisms present in the functional repair of neuronal injuries and which can be induced by the use of a BCI in the rehabilitation of sensorimotor function for patients with stroke and trauma brain injury with brain damage [3,4]. In order to control or induce neuronal plasticity to restore sensorimotor functionality, we first need to understand how neurons respond to stimuli and encode/decode the signals that characterize the formation of neuronal circuits. With that being said, an effective BCI must be able to both encode and decipher the actual encoding of neuronal circuits likewise, so as to provide a gateway between the patient's brain and the BCI itself. In recent research, brain data input were gathered using a electrodes microarray implanted directly in cortical surface of the brain which offer 100 individual channels each one associated to a specific neuron response [5], although processing these amount of data reassemble like complex task.Up-to-dated studies have been making use of Artificial Neural Networks to classify signal patterns throughout neuronal circuits in order to command movements [6,7] . Artificial Neural Network (ANN) is a Machine Learning technique that mimics the functioning of a neuron and is widely used in Computer Science to train machines to perform tasks or make decisions based on pattern classification.

The objective of this study is to draw a literature review on the role of neuroplasticity-induced brain-machine interfaces in the rehabilitation of patients with neuronal damage, especially those using ANN to decoder human neuronal input.

METHODS

The following databases were consulted: MEDLINE, Cochrane VHL, SciELO and PubMed, were consulted using the keywords: Neuronal Plasticity combined with Brain-Computer Interface. The search was limited to English language articles. Articles identified by the initial search strategy were evaluated by two authors independently as inclusion criteria: (1) Intervention (use of brain-computer interfaces), (2) population (patients with direct or indirect brain damage with motor or cognitive impact), (3) Relationship with neuronal plasticity. Exclusion criteria were: articles in which there was disagreement between authors; articles which had repeated information or available in other items. The quantitative data resulting from search and analysis of the articles are in TABLE 1.

Table 1. Quantitative data results from searching and final analysis of reviewed artticles.

	MedLine	Cochrane BVS	Scielo	PubMed	**Total**
Initial Search	21	0	0	61	82
First Analysis	5	0	0	8	13
Final Decision	3	0	0	4	7

BCI TRAINING WITH ARTIFICIAL NEURAL NETWORKS

Some studies have applied Artificial Neural Networks to the task of decoding the signals emitted by neurons which are part of neuronal circuits responsible for movement and decision making [6,7]. This application signifies the obsolescence of intensive end user training of the BCI, since the neural net algorithm, called Backpropagation, is now in charge of learning which group of signals is responsible for each action in an automated fashion, enabling the catalogation of different patterns as commands that are recognized by the time the patient is making use of the BCI. Artificial Neural Networks try to imitate the functioning of actual neurons. A neural net is a feedforward network that contains 3 layers: input layer, with n_{inout} units; hidden layer, with n_{hidden} units; and output layer, with n_{output} units. Every connection in the net has an activation function called the Sigmoid Function, given by Equation (1), which is a representation of the firing rates of neurons, and an associated initial weight ω_i (initialized randomly in with a small value and associated with each element of the signal).

$$F(u) = \frac{1}{1+e^{-u}} \text{ ,where } u = \sum_{i=0}^{n} \omega_i x_i \quad (1)$$

The algorithm's input is a dataset of signals from actual neurons recorded by invasive or noninvasive techniques (such as

EEG), properly preprocessed so as to facilitate classification [7]. Until the termination condition is met, the following steps are repeated:

1. Each neuron u in the network receives a component of the vectorized version of the signal previously recorded and experimentally labeled as being responsible for a certain movement, denoted as the pair $< x, t >$, where t is the signal's label or class), then the activation function *F(u)* for each one is calculated, according to (1).
2. The error function is calculated and the errors are propagated back to
   a. each output unit k in the output layer, calculating its error term δ_k as in Equation (2):

$$\boldsymbol{\delta_k = o_k(1 - o_k)(t_k - o_k)} \qquad \textbf{(2)}$$

   b. Each hidden unit h in the hidden layer, calculating its error term $\delta_h$as in Equation (3):

$$\boldsymbol{\delta_h = o_h(1 - o_h) \sum_{k\epsilon outputs}^{n} \omega_{kh}\delta_k} \qquad \textbf{(3)}$$

3. Update the network weights ω_{ji} as in Equation (4):

$$\boldsymbol{\omega_{ji} = \omega_{ji} + \Delta\omega_{ji}, \text{ where } \Delta\omega_{ji} = \eta\, \delta_j x_{ji}} \qquad \textbf{(4)}$$

The Backpropagation algorithm attempts to classify all the signals correctly with regard to the target classification, t, for each signal the network receives as input, by minimizing the error between its computed output and the actual target value. A common termination condition for the algorithm is a fixed percentage of all signals being accurately classified.

With this technique, the BCI learns which signals are responsible for each movement, which the patient can simply think of doing or actually try to perform it, and the BCI performs the task of transmitting that intention to the corresponding member of the body or prosthetic equipment the patient intends to make make use of [6,7].

PLASITICTY INDUCE BY BRAIN COMPUTER INTERFACE

Using BCI devices is a way of communication with the outside world completely new to the brain, for which user training is necessary[8]. The training induces neuronal plasticity very close to that observed in the construction of memory and learning and results in changing the firing pattern of a neuron population [3,9].

Evidence suggests that change that occurs is the reorganization of the firing pattern of some individual neurons responsible for error engine tuning, and not only the behavioral strategy [9,10,11]. In addition, experiments with two-hand control show that the plasticity induced by the training creates motor representation in the same population of neurons simultaneously, especially in the primary motor cortex (PMC), which is why most of the candidates for the use of BCI must have PMC intact. Still, basically any cortical area has the potential to be exploited by this technology [1,7,8] .

It was also observed that in BCI devices using Neurofeedback (NFB), especially for Transcranial Magnetic Stimulation induce earlier, the plasticity mechanisms should be already observed in the first 30 minutes of training (Fig. 1) because it provides the population neuronal a parameter for engine error setting [7].

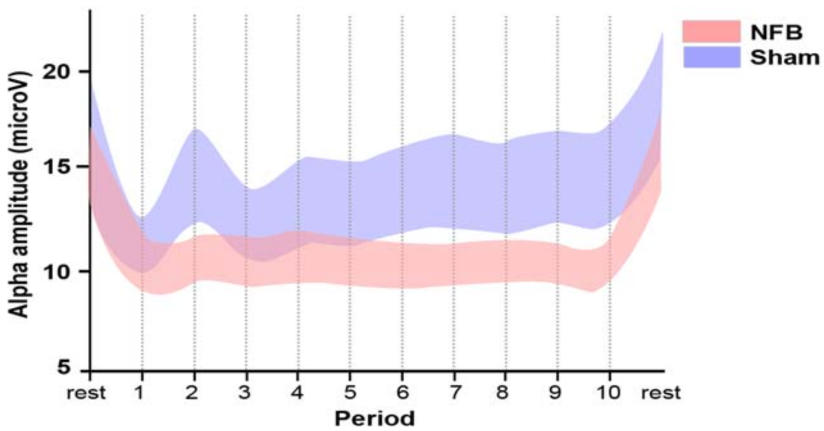

Figure 1. graph showing the variation of alpha waves throughout the experiment. The objective given to patients was to reduce the alpha waves. NFB – Neurofeedback induced group. NFB can archive it faster.

Conclusions

BCI allows a whole new way for the brain to communicate with the outside world. The literature shows strong evidence that neuronal plasticity plays a key role, through the reorganization of neuronal population and individual patterns as well as changing the behavioral strategy, both in BCI uni or bi-manual, especially in the primary motor cortex; and plasticity induced by their use is more effective in models based on BCIs associated with Neurofeedback. Thus, this technology is a great choice for rehabilitation of patients with cortical, peripheral nerve or muscle damage, although it is still very expensive and quiescent for broad clinical use. There's no evidence comparing efficiency of analysis method of neuronal gathered data. However, ANN is a good method of data analysis because of its versatility on real-time learning process and adaptation to patient gathered data, such as cortical neuron groups' patient does.

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