Portable device for transcranial direct current stimulation (tDCS) for use in home electrotherapy

Kristina Tomović
Faculty of Electrical Engineering
University of Montenegro
Podgorica, Montenegro
kristinatomx@gmail.com

Ana Šćekić
Faculty of Electrical Engineering
University of Montenegro
Podgorica, Montenegro
ana.scekic96@gmail.com

Abstract— **This paper briefly describes several important approaches in electrotherapy treatment, with special reference to the methods of applying non-invasive direct currents of small strengths in treatments of transcranial direct current stimulation, then presents the initial research that will serve scientifically and in the practice of further work as a basis and necessary preparation for developing and making a prototype of portable electrotherapy device for transcranial stimulation using direct currents, feasible in home conditions. The paper presents previous experimental results and provides an overview of possible future achievements and further development in suggested direction.**

Keywords— electrotherapy, transcranial direct current stimulation (tES, tDCS), cortical excitability, brain-derived neurotrophic factor (BDNF), brain disorders, neurodegenerative diseases, home therapy, portable device

I. Introduction

A. Definition

For the last two and a half centuries, doctors, scientists, philosophers and even laics tried to improve the ancient medical science with various medical and supermedical methods, successful and unsuccessful scientific research, experiments on living and non-living human beings and animals, as well as by using various recognized medical treatments. The latest treatment trend that shows fast and good results is based on a completely "natural" resource and is just in the initial slow stages of research and application. The word here is about the treatment with electric current, called electrotherapy.

Electrotherapy is a segment of physical therapy that refers to medical treatments that use electric currents for the purpose of treating certain conditions and injuries of the patients. By applying electricity to the injured tissue, the blood vessels expand thus increasing blood and lymph circulation, nerve endings are better stimulated, pain pathways are inhibited, while the overall tissue metabolism is stabilized and improved. [1]

The historical origins of transcranial electrical stimulation (tES) use as a therapy follow the history of the discovery of electricity itself. Though with dose bearing little resemblance to modern techniques, early attempts utilized electrosensitive animals such as torpedo fish and examined the effects of electrical discharge over the scalp on headache pain reduction. With the development of man-made electric sources, studies in the 19th and early 20th centuries implemented the use of non-invasive direct - galvanic currents in the treatments of psychiatric disorders and similar brain disfunctionalities. [2]

Transcranial electrical stimulation (tES) is a non-invasive brain stimulation technique that applies electric current through the brain cortex with the aim of influencing brain function, resulting in inhibition or enhacement of brain activity. By applying two or more electrodes to the patient's scalp, mostly placed in saline-soaked sponges to ensure better conductivity, a non-invasive weak current reaches the soft tissue and skull, resulting in a relaxing effect with expected benefits.

Transcranial electrical stimulation (tES) comprises a number of different techniques, including transcranial direct current stimulation (tDCS), alternating current stimulation (tACS) and random noise stimulation (tRNS). Whilst these techniques are similar in most ES applied patterns, their methodology, behavioural and neuronal outcomes, differ. In contrast to transcranial magnetic stimulation (TMS), the current delivered in these tES techniques is not in high enough intensity to elicit an action potential and is maintained at subthreshold levels to effect cortical excitability only. [3]

B. Transcranial direct current stimulation (tDCS)

Cortical excitabilty, as a fundamental aspect of human brain function, is defined as the strength of the response of cortical neurons to a given stimulation. According to many so far research, cortical excitability can also be defined as the electrical reactivity of cortical neurons to a direct perturbation and is directly affected by the duration of wakefulness of the patient and is significantly modulated by circadian phase that reffers to the rhythms of physical, mental, and behavioral changes in a 24-hour body activity cycle of a patient. [6]

Transcranial direct current stimulation (tDCS) uses a low direct current of intensity of just 0.5–2 mA, where mostly only current of intensity above 1.5mA have satisfying results, and is generating an electrical flow from one or more active anodes, through the applied area of the head, to a reference cathode, where this flow of electrical energy, considered just as a needed portion out of the big amount applied in the treatment, quickly results in cortical excitability. In this way, the motor potential of the cortex increases, whereby the low intensity of the applied electric field allows the neuronal transmembrane potentials to be modified and trigger excitability, thereby bringing the underlying neurons closer to their firing threshold without causing depolarization. Depolarization of neurons means that under the influence of some outside stimulus, sodium channels are opening, leaving the Natrium ions enter the neuron membrane, thus changing the polarity of membrane potential from negative to positive. In this process of depolarization of neurons strong nerve impulse are being generated which is resulting in big brain excitability and thus inhibition of symptoms of many neuropsychiatric diseases or unwanted movements as part of rare neuro disorders. Numerous studies have investigated the mechanisms that can affect brain in right healthy doses while treating neuro diseases of different levels and types. Specifically, tDCS has been shown to act by altering γ-aminobutyric acid concentrations (GABA) in charge for producing a calming effect for brain activity and playing a major role in controlling nerve cell hyperactivity associated with anxiety, stress and fear. Besides this, tDCS method is also increasing levels of brain-derived neurotrophic factor which promotes the survival, growth, maturation and maintenance of neurons. [4] [5]

Brain-derived neurotrophic factor (BDNF), also known as abrineurin protein, is in charge for regulating glucose and energy metabolism, while decreased levels of this protein cause neurodegenerative diseases with neuronal loss, such as Parkinson's disease, Alzheimer's disease, multiple sclerosis and Huntington's disease. [7] One of the research showed that BDNF increase is connected with anodal tDCS-induced enhancement of synaptic plasticity, where synaptic plasticity is defined as a process in which neuronal activity results in changes where connections between neurons are strengthening with aim to improve learning and memory within the hippocampus. While the anodal tDCS treatment is improving brain activity, on the other hand, cathodal tDCS shows good results in decreasing the neuronal excitability of the area being stimulated which is commonly used in treating psychiatric disorders with symptoms of hyper-activity of certain brain area. That is why tDCS plays a major role in improvement of brain function, thus being a right and least harmful medical treatment for many brain disorders.

II. Method

It is known that for a long time tDCS has been widely studied as an alternative pain control approach in the treatment of various neuropsychiatric syndromes and pathologies. Pharmacological approach is a common strategy in treatments, however, there are numerous reasons why mentioned alternatives are used more often, and they are: patients getting used to the drug, creating addiction, lack of effectiveness etc. In this context, tDCS represents a promising and safe alternative to medication.

In 2015, the British National Institute for Health and Care Excellence (NICE) introduced tDCS methodology to be both effective and safe treatment for depression. Analysis from 2016 in 2017 has showed that at least 40% of people treated with tDCS in order to treat depression, showed at least 50% symptom reduction.

In its setup, the tDCS procedure, in addition to the main device, requires the main – target electrode and the reference electrode, soaked sponges, saline solution or gel for the electrodes for a better conductivity, with the surface of the electrodes being 25 to 35 cm^2 (5 × 5 cm and 5 × 7 cm), and the distance between them at least 8 cm, in order to ensure the best possible passage of current through the cortex.

In most stimulations therapy lasts between 5 and 30 minutes. Longer sessions may cause changing polarity of neuron membrane, as previously mentioned in this paper, and thus lead to unwanted greater impulses and brain activity. The most common side effects observed with tDCS are mild tingling (70.6%), moderate fatigue (35.3%), sensations of light itching (30.4%), slight burning (21.6%) and mild pain (15.7%) under the electrodes.[9]

Research suggest that in order for stimulation to actively modulate cortical activity it should be above a minimum threshold of 0.017 mA/cm^2. Many studies had been using currents of intensity of 1.5 mA and 100 cm^2 size of reference electrode and 35 cm^2 size of target electrode, thus gaining current density of 0.043 mA/cm^2 which had resulted in an appropriate below threshold current density for the reference electrode, and above threshold for the active electrode.[8] Applied current density and the intensity of the therapy effects also depend on the duration of the stimulation, so before every treatment all of these factors should be examined in order to create perfect conditions for a pacient as an individual. At the same time and in order to deliver the exact and worthful therapy procedure, it is necessary to examine patient factors which include alertness, body rhythm, caffeine intake, wakefulness, etc. so that the threshold level can be approximately defined, as the polarity is in narrow relation with individual’s current state. Treatments of tDCS do not cause depolarization of neurons and at the same time are dealing with controlling the strong enough current intensity so that the expected effects could be seen.

Setup of the tDCS device should be always including a brain of the device, CPU unit that is receiving all the signals and then works with the results for different purposes.

Home therapy is announcing few new approcahes in the field of electrotherapy, but still not widely spread when it comes to transcranial methods in electrotherapy as they mostly require presence of a professional with aim to keep the safety and effectivness of the applied treatment to the highest levels possible. Among all the established methods used in transcranial electrotherapy, tDCS devices made for home therapy and independent use by a patient are commonly used, as the weak currents applied in these treatments cannot produce negative effects. Building the kind of electrical device that will fit up to these safety requests as well as succeed in generating strong enough intensity of needed current, and at the same time being easily used by a final user – patient is at the starter phases of research and studying presented in this paper.

III. DEMONSTRATION

There are few models of devices for tDCS treatments feasible in home conditions that can be currently found on the market, such as: so-called brain drivers – simple devices with rechargable battery and well adjusted hardware with the interface intended for easy setting the desired current intensity and stimulation duration, tDCS starter kits available both for home therapy and research, popular forehead bandages aimed for simple stress relief which are being used during gaming or studying, then anti-depression tDCS devices, etc.

In the following the schemes of two tDCS devices for electrotherapy treatments are presented. (Figure 1, Figure 2). Electric circuit of proposed tDCS device should be consisted of constant current source for proper current regulation which must be operated on batteries or a stable voltage source that can also be provided by USB port. There are three current switches for regulating the output current in Figure 1. Different treatment needs different current flow through the cortex. So, depending on the switches states, there are 4 different outputs: when all switches are OFF – open, the output current on the electrodes is 1 mA, when S_1 is ON, output is 2 mA, with switches S_1 and S_2 ON, the output is 3 mA, while with S_1 and S_3 ON, output current is 4 mA. Electrodes should be 4 x 4 cm and soaked in saline sponges. LED is a signal point that marks when the treatment starts, while the capacitors serve as circuit memory stations, holding the switches level in order to generate constant current on the output for the long enough time. (Figure 1)

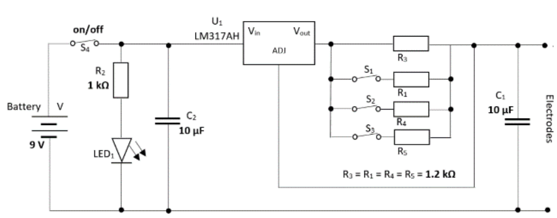

Figure 1: tDCS scheme, battery powered device

Figure 2 shows the scheme of USB powered tDCS device which uses voltage converter along with voltage regulator, where boosted voltage of intensity of 12 V is being regulated so that the output current could be in 0.5 – 2 mA range.

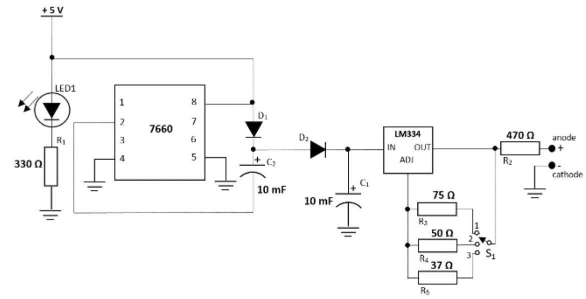

Figure 2: tDCS scheme, USB port powered device

IV. RESULTS

Paper observed both medical and tehnical backgrounds that would serve in further study and building one of a kind simple tDCS device prototype that will be easy accessible for home therapy of treating several brain diseases including Parkinson's disease, Alzheimer's disease, different types of depression, etc.

In the Figure 3 example of FDG-PET image is shown, where it refers to fluorodeoxyglucose (FDG)-positron emission tomography (PET), taken from a patient underlying tDCS treatment, with two different images representing two patient's conditions: before therapy treatment (pre-therapy) and after therapy (post-therapy), in order to map glocose metabolism. The white arrow indicates the right thalamus, the area with the greatest difference between the images. The color bar describes increasing FDG uptake with increasing signal intensity, from black, indicating no glucose uptake, to red, indicating the greatest glucose uptake. [10]

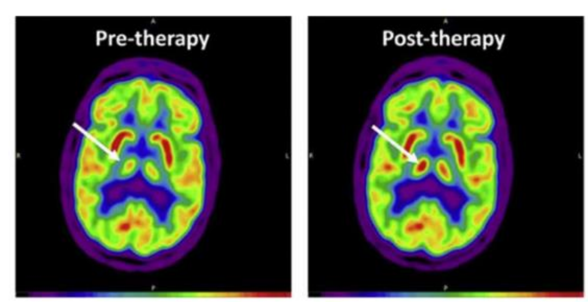

Figure 3: tDCS FDG-PET transaxial image acquired pre- and post-tDCS therapy [10]

Proposed approach results in aim to build such easy portable device for independent performing of tDCS treatment in home conditions, by an individual that is actualy a patient himself, but at the same time paying attention to provide high levels of safety along with constructing and programming the simple interface with light and compact hardware packaging. Proposed example is shown in Figure 4.

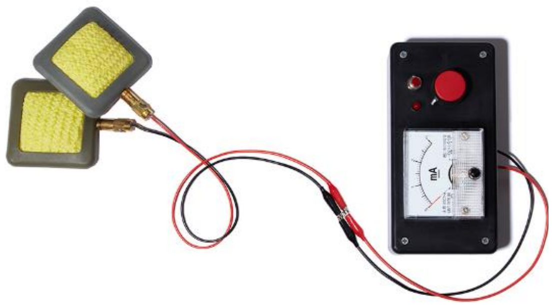

Figure 4: Proposed example of tDCS portable device for home therapy medical treatments [11]

V. CONCLUSION

Telemedicine approach now enables easy communication with patient and performing adequate treatment from any distance, but also monitoring patient's condition in any measurable cycle, which does not require effort for either the patient or the doctor, while on the other hand numerous electronic functions perform precise measurements of the patient's condition, while storing loaded data. In the field of physiotherapy, which uses electronic devices to perform the treatments, the use of simple devices for performing electrotherapy in home conditions, which are completely safe and cannot have a harmful effect on any segment of the body, is still not widespread. Future work on this topic will deal with the creation of a prototype of a portable device for performing tDCS treatment in electrotherapy, which can also have a convenient interface for communicating with the doctor, i.e. connecting to smart mobile devices that the patient uses on a daily basis, such as a mobile phone, personal computer, tablet device. Further work in this direction would require the improvement of the hardware itself, in order to make the device more compact and suitable for unhindered use by all generations of users of various medical treatments.

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