

The Utility of Transcranial Electrical Stimulation in Patients with Memory and Emotion Disorders after Brain Damage — Current Scientific Data and Own Experiences

Przydatność przezczaszkowej stymulacji elektrycznej u pacjentów z zaburzeniami pamięci i emocji po uszkodzeniu mózgu — aktualne dane naukowe i doświadczenia własne

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Abstract

Traumatic brain injury (TBI) and cerebrovascular incidents (CVA) lead to numerous neurological deficits, including cognitive and emotional deficits. Transcranial direct current stimulation (tDCS) is gaining prominence as a method to help rehabilitate cognitive function and regulate emotions, offering a non-invasive and safe therapeutic approach. The aim of this paper is to analyze the current scientific data and own experiences according to the effectiveness of tDCS in the rehabilitation of patients after TBI and CVA with memory and emotion disorders. A literature review (2015–2024) was conducted, including clinical trials, meta-analyses, and systematic reviews (PubMed, Scopus, and Web of Science). The papers on the use of tDCS in the modulation of cognitive and emotional functions in neurological patients were analyzed. Particular attention was paid to the mechanisms of tDCS action, stimulation protocols (intensity, electrode location, treatment time), and clinical outcomes in terms of memory improvement, emotion regulation, and reduction of depressive symptoms. Studies indicate a beneficial effect of tDCS on neuronal plasticity and cognitive and emotional functions of patients after TBI and CVA. Combined therapy (tDCS and rehabilitation) shows greater effectiveness than traditional methods, leading to faster improvement of working memory, reduction of emotional lability and reduction of depression symptoms. It has also been shown that the effectiveness of tDCS depends on the location of electrodes and individual patient characteristics. The best results were obtained with protocols including 20–30 minute sessions at 1–2 mA intensity, conducted 5 times a week for 3 to 6 weeks. Anodal stimulation over dorsolateral prefrontal cortex (DLPFC) or motor cortex (M1) was the most commonly used method, resulting in significant improvement in both cognitive functioning and emotion regulation. tDCS treatments are a promising tool supporting neurorehabilitation of patients with memory and emotional disorders after brain injury. Combining tDCS with speech therapy may contribute to more effective restoration of cognitive and emotional functions. Further studies are needed to optimize stimulation parameters and standardize therapeutic protocols. (JNNN 2025;14(4):182–192)

Key Words: cognitive rehabilitation, emotional disorders, head injury, neurorehabilitation, stroke, transcranial direct current stimulation (tDCS)

Streszczenie

Urazowe uszkodzenia mózgu (TBI) oraz incydenty mózgowo-naczyniowe (CVA) prowadzą do licznych deficytów neurologicznych, w tym poznawczych i emocjonalnych. Przechaszkowa stymulacja prądem stałym (tDCS) zyskuje na znaczeniu jako metoda wspomagająca rehabilitację funkcji poznawczych i regulację emocji, oferując nieinwazyjne i bezpieczne podejście terapeutyczne. Celem niniejszego artykułu jest analiza aktualnych danych naukowych i własnych doświadczeń dotyczących skuteczności tDCS w rehabilitacji pacjentów po TBI i CVA z zaburzeniami pamięci i emocji. Przeprowadzono przegląd literatury (2015–2024), w tym badań klinicznych, metaanaliz i przeglądów systematycznych (PubMed, Scopus i Web of Science). Przeanalizowano prace dotyczące zastosowania tDCS w modulacji funkcji poznawczych i emocjonalnych u pacjentów neurologicznych. Szczególną uwagę zwrócono na mechanizmy działania tDCS, protokoły stymulacji (intensywność, umiejscowienie elektrod, czas leczenia) oraz wyniki kliniczne w zakresie poprawy pamięci, regulacji emocji i zmniejszenia objawów depresji towarzyszącym stanom po uszkodzeniu mózgu. Badania wskazują na korzystny wpływ tDCS na plastyczność neuronalną oraz funkcje poznawcze i emocjonalne pacjentów po TBI i CVA. Terapia łączona (tDCS i rehabilitacja) wykazuje większą skuteczność co do szybszej poprawy pamięci operacyjnej, zmniejszenia labilności emocjonalnej i zmniejszenia objawów depresji. Wykazano również, że skuteczność tDCS zależy od lokalizacji elektrod i indywidualnych cech pacjenta. Najlepsze wyniki uzyskano w przypadku protokołów obejmujących 20–30 minutowe sesje o natężeniu 1–2 mA, przeprowadzane 5 razy w tygodniu przez 3 do 6 tygodni. Najczęściej stosowaną metodą była stymulacja anodowa grzbietowo-bocznej kory przedczołowej (DLPFC) lub kory motorycznej (M1), co skutkowało poprawą funkcjonowania poznawczego, jak i regulacji emocji. Zabiegi tDCS są obiecującym narzędziem wspierającym neurorehabilitację pacjentów z zaburzeniami pamięci i emocji po uszkodzeniach mózgu. Połączenie tDCS z terapią mowy może przyczynić się do skuteczniejszego przywrócenia funkcji poznawczych i emocjonalnych. Konieczne są dalsze badania w celu optymalizacji parametrów stymulacji i standaryzacji protokołów terapeutycznych. (PNN 2025;14(4):182–192)

Słowa kluczowe: rehabilitacja poznawcza, zaburzenia emocjonalne, uraz głowy, neurorehabilitacja, udar mózgu, przechaszkowa stymulacja prądem stałym (tDCS)

Introduction

The consequences of brain damage during traumatic or stroke episodes continue to be a significant and multidisciplinary challenge for modern medicine. The effects of such episodes affect the daily functioning of patients, taking into account the aspect of both limited physical fitness, but also a number of neuropsychological, behavioral, cognitive, and emotional changes. In light of the latest research results in the field of neuropsychology, the importance of the size and location of brain damage, the time since the episode, as well as physical and intellectual impairment and social factors are emphasized as key to emotional disorders. Studies on brain damage causing deficits in the processing of pragmatic information have provided evidence that cortical areas in both cerebral hemispheres may be key to understanding even basic communication disorders. It has been proven that damage to the frontal lobes leads to a serious disorder in the formation of intentions, plans, behavior and disturbances in the regulation of mental activities.

Post-traumatic brain injuries can lead to disorders including personality changes, dementia, emotional or behavioral dysregulation, and cognitive deficits and depression, which effectively hinder the neurorehabilitation process. In turn, emotional changes associated with strokes can be caused by the patient's brain damage itself or be the result of increased neuropsychological reactions. These various emotional disorders in the context of damage to the central nervous

system are pathophysiologically related, and early and precise neuropsychological diagnostics play a key role in planning therapeutic actions.

The aim of this paper is to critically analyze current scientific evidence and present the authors' own clinical experiences regarding the effectiveness of transcranial direct current stimulation (tDCS) in the rehabilitation of patients after traumatic brain injury (TBI) and cerebrovascular accidents (CVA) with memory and emotional disorders. A particular emphasis is placed on the neurophysiological mechanisms of tDCS, stimulation protocols, clinical outcomes related to cognitive and emotional functioning, and the practical applicability of tDCS as a complementary intervention within multidisciplinary neurorehabilitation programs.

Emotion Regulation after Brain Damage

It has been shown that difficulties in emotion regulation are one of the most common and most burdensome consequences of acquired brain injury, resulting from traumatic brain injuries (TBI) or cerebrovascular disorders accidents (CVA) — strokes. They have potentially harmful and long-term effects in all areas of life [1]. Impaired emotional regulation may lead to deterioration of social functioning, reduced leisure time activity, inability to return to work, or the development of depressive symptoms and increased risk of suicide [2].

Emotional regulation is closely linked to the ability to flexibly modulate and control the subjective experience and expression of emotions and to reduce emotional arousal [3]. In cases of brain damage, as a consequence of TBI or CVA, in addition to the impaired ability to differentiate emotions, self-control and control may be impaired, which is revealed by various symptoms of emotional dysregulation, including inhibition of emotions/behavior and reduced emotional awareness and expression [4]. Furthermore, emotional regulation is an important aspect of executive functioning [5], broadly described as interconnected top-down processes promoting the control and regulation of cognition, behavior, and emotions. In contrast to the view that TBI is directly responsible for emotional dysregulation, it may also be a secondary response. It is important to emphasize that the experience of cognitive deficits after brain damage has been described as having a “disorganized” mind, referred to as a situation that can be emotionally experienced as a chaotic internal state. Adding further layers of complexity, co-occurring emotional problems may also influence symptom presentation following brain injury in TBI or CVA [6,7].

Emotional Disorders after Brain Damage

People with brain damage, as well as mentally ill people, who reveal emotions and moods, can be easily classified as disorders. However, the experience gained from psychiatry and from the anti-psychiatry movement dictates that, first of all, the patient’s reactions should be considered in normative categories, i.e. as an expression of adequate, extreme experiences of situations, emotions and moods. Extreme situations are created by imprisonment, restriction of freedom, compulsory treatment or “imprisonment in the body” characteristic of people with brain damage. Such an approach requires, first of all, determining the patient’s psychological situation and understanding their experiences against this background. Only secondly, when the situation does not sufficiently justify the depth of emotions or moods, one can attempt psychopathological categories of emotional disorders or affective disorders, including depression [8].

The impact of brain damage on the emotional system is, as Gainotti notes [9], twofold: on the one hand, if the limbic system or other parts of the brain related to it, for example the lower, medial part of the frontal lobes, are damaged, which is not uncommon in brain injuries, then the emotional system may be dysfunctional at the functional and structural level. On the other hand, experiencing a brain injury always brings with it traumatic experiences, not at all indifferent to the patient’s mental

life, who may feel in various ways that his life has been radically changed.

Every serious disease or injury has a characteristic negative impact on the patient’s emotional state, but in brain injuries the situation is invariably complicated by the fact that the very system in the body that is responsible for emotional processes may be damaged [10]. When emotional disorders appear in the patient’s behavior after a brain injury, it should be assumed that we are taking into account neurological, physical, and psychological causes. However, it is not easy to determine the mutual relationship of these factors in a specific case, as well as their relative proportion [11,12].

Among the various categories of diseases that can cause brain damage, the best evidence of the relationship between structural changes in the brain and emotional disorders is the one that shows it. This is due to the fact that in patients after a typical road accident, in which acceleration and deceleration occurred, the axial structures of the brain and the basal and medial parts of the frontal and temporal lobes are most often damaged [13,14]. Therefore, the cortical and subcortical structures are particularly susceptible to damage, which, as is known, play a very important role in various emotional aspects. The clinical evidence of this statement is the well-known predominance of emotional and neurobehavioral disorders compared to motor, sensory or aphasic disorders in patients after brain injury compared to patients after stroke [15].

Post-stroke and Post-traumatic Brain Injury Disorders

In relation to TBI, they can lead to disorders including personality changes, dementia, emotional or behavioral dysregulation, and persistent cognitive deficits. The most common post-traumatic neurological sequelae include cerebraesthesia and encephalopathy or seizures. The nature and severity of disorders in the course of TBI is very diverse due to the type of injury, location, and extent of damaged brain tissue [16]. Complex pathophysiology resulting from primary and secondary injuries developing over minutes, days, and months can lead to transient or permanent emotional deficits [17]. Injuries in specific brain areas may be associated with certain symptoms or syndromes, e.g. temporo limbic damage with aggressive behavior and epilepsy, subcortical damage to the brainstem with reduced alertness and disorientation, and damage to the frontal lobes with inhibition, aggression, emotional lability, and personality changes [18]. However, most TBIs, especially closed TBIs, which are more common than penetrating TBIs, tend to cause more diffuse brain injuries with varying types and degrees of damage [19].

In the case of CVA, emotional problems occurring during the acute phase of stroke are not of particular concern to medical personnel, although it is well known that anxiety and depression are common and affect neurological outcomes in patients [20]. Emotional changes associated with CVA may be caused by the patient's brain damage itself or may be the result of neuropsychological reactions [21]. Regardless of the mechanisms explaining the emotional problems associated with CVA, early identification and treatment of anxiety and depressive symptoms may prevent more serious neurological outcomes in this group of patients. Moreover, the emotional stress and personal suffering of patients may be alleviated when more resources are directed to these problems, both in the acute and chronic phase [22]. To date, studies on emotional disorders such as anxiety and depression in stroke patients have focused on symptoms occurring during the rehabilitation period, from several months to several years after the onset of stroke symptoms [23]. Mood and emotional disorders are common symptoms in people after CVA. These symptoms are unpleasant for both patients and their caregivers and negatively affect the quality of life of patients [24]. Important mood and emotional disorders include depression, anxiety, emotional lability, tendency to anger and fatigue. The factors underlying and predictors of these emotional disorders partially overlap. The relationships between these phenomena and the location of pathological changes vary depending on the individual emotional symptoms. Therefore, these various emotional disorders in the context of CNS damage are pathophysiologically related, and early and precise neuropsychological diagnostics and neurophysiological tests are crucial for planning therapeutic actions.

Potentials of Non-invasive Brain Stimulation

Electrical brain stimulation to induce and modulate the excitability and activity of the cerebral cortex has a long history, dating back several hundred years [25]. Initial methods aimed to induce suprathreshold stimulation of neurons in order to generate neuronal activity and thus appropriate physiological, motor, or psychological effects. The breakthrough in noninvasive electrical brain stimulation in humans occurred in 1980, when it was shown that short, strong electrical pulses applied over the motor cortex could induce muscle convulsions [26]. Transcranial direct current stimulation (tDCS) is fundamentally different from these initial, suprathreshold methods, as it is based on a completely different — subthreshold modulation of neuronal membrane potentials. tDCS stimulation is too weak to induce neuronal activity independent of afferent signals from other sources, but sufficient to change both

excitability and spontaneous neuronal activity [27]. The tDCS method, commonly referred to as electrical micropolarization of the brain, is a method of non-invasive brain stimulation consisting in non-invasively passing a weak electric current of 1–2 mA intensity through the cerebral cortex using at least two electrodes located on the surface of the skull.

Neural Mechanisms of Action of tDCS

The tDCS method has recently been intensively evaluated for use as a tool for modulating cognitive functions and symptoms of psychiatric and neurological disorders [28]. The tDCS method has significant therapeutic potential due to its relatively low cost, convenience, safety, and ease of use compared to other neuromodulation methods [29]. Adverse effects such as itching, burning sensation, or headache are common but generally mild and do not have a long-term effect on the patient [30]. Therefore, tDCS compares favorably with other therapeutic methods such as antidepressants or even repetitive transcranial magnetic stimulation (rTMS) [31]. It should be emphasized that the method of electrical micropolarization of the brain still requires in-depth research to determine its full potential as a reliable, safe and effective scientific and clinical tool [32]. As the number of studies has increased rapidly in recent years, several key unresolved issues have emerged as priority research topics that need to be addressed in order to make further progress in this field [33].

Considering the whole brain, there is converging evidence that tDCS induces changes in cortical excitability and activity. For example, using the primary motor cortex (M1) as a model region, when the anode is placed over M1, tDCS increases spontaneous activity and excitability of this region. Conversely, when the cathode is placed over M1, spontaneous activity and excitability are reduced [34]. Therefore, transcranial electrical stimulation with a weak current may be a promising tool to modulate brain excitability in a noninvasive, painless, reversible, selective, and focal manner, which suggests an additional therapeutic advantage — precision of action. In the human model, neuromodulation-related effects occur within the first 4 seconds of stimulation, which does not induce aftereffects. However, this finding is either due to the observation of activity of many cells using motor-evoked potentials as a proxy for cortical excitability. It is therefore a summative effect over many thousands of neurons; single neurons oriented differently in relation to the electric field may respond in a different, even opposite, way [35].

While the early effects of tDCS, induced by a few seconds of stimulation, do not persist for a longer period of time, longer-lasting stimulation induces after-effects

in the primary motor cortex (M1). These after-effects can last from a few minutes to more than 24 hours after the intervention, depending on the methodology and the therapeutic protocol used. In general, the directionality of the after-effects of tDCS is identical to that observed during stimulation: in standard protocols applied to the primary motor cortex, anodal tDCS (A-tDCS) increases, while cathodal stimulation (C-tDCS) decreases cortical excitability. Within certain limits, stronger and longer tDCS stimulation enhances the efficacy of these effects [36].

Mechanism of Neuronal Plasticity in tDCS

The above is a summary of hypotheses regarding the main mechanisms by which tDCS induces neuronal plasticity. However, a number of other neurotransmitters and neuromodulators, such as dopamine, adenosine, serotonin, and acetylcholine, may be involved in this process [37]. For example, blockade of dopamine receptors and specific adenosine receptors has been shown to prevent tDCS-induced plasticity [38]. Indeed, modulation of the activity of different groups of neurotransmitters has a distinct but complex effect on the effects obtained during tDCS.

It is known that cortical areas other than M1 also undergo tDCS-induced neuroplastic changes, leading to short- and long-term changes in synaptic potential [39]. However, in early animal experiments, the effect of tDCS on, for example, the visual cortex was less pronounced than on the M1 motor cortex. This is probably due to the different cytoarchitecture of these cortical areas and the different spatial orientation of the neurons. Human studies, conducted almost 40 years later, confirmed these results, showing that the after-effects of tDCS are relatively short-lived in visual areas compared to M1 areas, using the same tDCS stimulation protocols [40].

Clinical application of tDCS in neurology

A group of European experts commissioned by the European Chapter of the International Federation of Clinical Neurophysiology collected information on the state of knowledge on the therapeutic use of transcranial brain micropolarization tDCS from studies on pain, Parkinson's disease, other movement disorders, stroke, post-stroke aphasia, multiple sclerosis, epilepsy, disorders of consciousness, Alzheimer's disease, tinnitus, depression, schizophrenia and craving/addiction [28]. Current evidence does not allow for a level A recommendation (definite efficacy) for any indication. A level B recommendation (probable efficacy) is proposed for:

(1) A-tDCS of the left primary motor cortex (M1); (2) A-tDCS of the left dorsolateral prefrontal cortex (DPRFC); (3) A-tDCS of the left dorsolateral prefrontal cortex (DPRFC), dorsolateral prefrontal cortex (DLPFC) in non-drug-resistant major depressive episode; (3) A-tDCS of the right DLPFC in addiction. Level C recommendation (possible efficacy) is proposed for A-tDCS of the left M1 in chronic neuropathic pain of the lower limbs secondary to spinal cord injury. In turn, level B recommendation (probable ineffectiveness) results from the lack of clinical effects for: (1) A-tDCS of the left temporal cortex in tinnitus; (2) A-tDCS of the left DLPFC in drug-resistant major depressive episode [28].

It is worth adding that with the successively increasing number of studies on tDCS, an important question arises regarding the typical effects of stimulation on cognitive and cognitive functions that can be expected [33]. There are several recent examples of unsatisfactory reports based on meta-analyses in the literature. In particular, the relatively small sample sizes in most studies in the tDCS literature may be problematic, given that estimates of behavioral effect sizes are often moderate or small. Type I and type II error rates are not well-classified because the studies are relatively weak. This problem has been identified in analyses of the effects of tDCS on cognitive functions [41], but it also applies to other fields. This scenario poses a challenge to establishing the parameters of tDCS that can reliably affect cognitive and behavioral functions, mainly because the types of studies that are routinely conducted often lack sufficient methodological quality to provide adequate evidence. Moreover, conducting meta-analyses may be hampered by the methodological heterogeneity of the literature, which either limits their scope or forces them to combine heterogeneous studies that may not be directly comparable and thus underestimate the true effect size [42]. There is a need to conduct further, well-designed clinical trials with neuropsychological assessment in terms of emotional level and cognitive functions, which was the main assumption of this scientific project within the presented dissertation.

Methodology of tDCS Treatments in Memory and Emotion Disorders

For tDCS brain micropolarization procedures in patients with memory and emotion disorders after brain damage due to stroke and head injuries, certified devices such as the dual-channel tDCS stimulator (Soterix Medical Inc. Woodbridge, NJ, USA) can be used [43]. Micropolarization procedures are performed and supervised by neurorehabilitation and speech therapy specialists, people with competence and experience in tDCS, with training in neuropsychological diagnosis,

in the use of EEG — biofeedback, so-called neurofeedback, and tDCS stimulation. Based on our experience, brain micropolarization treatments is usually performed in three panels over five months — in the first (I), third (II) and fifth (III) months, including 5, 7 and 10 days of daily sessions lasting 30 to 40 minutes. Below is a detailed schedule of therapeutic panels, including individual sessions, treatment parameters and electrode locations (Table 1).

Patients qualified for tDCS neurorehabilitation after initial diagnostics of nervous system damage and nervous function disorders have an individual model of neurorehabilitation and speech therapy exercises implemented. As part of the standard procedure, speech therapy rehabilitation is implemented, planned and conducted by a qualified and experienced speech therapy specialist. Speech therapy, depending on the severity of the case, lasts from 30 to 40 minutes. Speech therapy concerns patients with aphasia, dysarthria, as well as partial disorders of swallowing, phonation and breathing reflexes. Rehabilitation is most often carried out using headphones and playing materials from DVDs related to articulation, impression, naming objects, describing them and reading with the participation of microphones. In the case of impaired speech motor skills, actions are focused on improving speech articulation using appropriate auxiliary equipment such as headphones, microphones, tablets, laptops, or speech therapy labiograms. Speech therapy boards and labiograms of all the sounds of the alphabet are helpful in practicing the correct positioning of articulators when pronouncing all the sounds, especially those that are impaired and cause the patient the greatest difficulty. In the case of patients with sensory speech disorders, photographs and graphics are also used, as well as everyday objects. Sets of ready-made exercises developed by speech therapy and pedagogical industry publishers are also used, intended for speech therapy and cognitive functions of patients with CNS damage. The auditory processing method can also be used, which causes additional involvement of the patient in listening to words read by the speaker. Memory exercises, consolidation of spatial

relations, writing sounds along the trace, as well as reproducing the reading process are used [44].

Scientific Evidence and Research Directions

Liege deserves special mention (triple blinding of patients, those conducting procedures and measurements, and statistically analyzing the data), the results of which were published in March 2020. Bornheim et al. [45] conducted a prospective, randomized clinical trial (RCT), with a triple-blind trial and long-term follow-up. Initially, 915 patients after stroke were recruited, of whom only 50 participants were ultimately selected (31 people withdrew from the project, and 266 patients were excluded due to advanced age over 80 years, 41 due to non-specific migraine headaches, 97 due to transient ischemic events, 107 due to hemorrhagic stroke, 142 due to unclear clinical picture, 31 due to history of alcohol and/or drug addiction, and 150 people due to the occurrence of amnestic syndrome). Then, the patients were randomly assigned to one of two comparative groups. All participants received a standard treatment program in the form of motor rehabilitation and occupational therapy. Physiotherapy lasted two hours a day, five days a week (Monday to Friday). In addition to motor rehabilitation, patients from the experimental group (N=25) underwent tDCS procedures. Electrodes with a surface area of 25 cm² were placed in the area of the primary motor cortex on the side of the lesion (anode) and in the area of points C3/Fp2 or C4/Fp1 (cathode). The procedures were performed five times a week for a month. Stimulation lasted 20 minutes at 1 mA, with a 15-second increase and release of impulses. The second group (N=25) received sham therapy. The Wolf Motor Function Test (WMFT), the hand motor skills test according to the Fugl-Meyer scale, the depression and anxiety scale (HADS) and the Barthel index (BI) were used to assess the therapeutic effects. Results were measured 48 hours after stroke, one week, two weeks, three weeks and four weeks, and then as long-term results (so-called follow-up) after three and six months and one

Table 1. Summary of tDCS session parameters and methodology

Panel [No.]	Time procedure [min]	Intensity current [mA]	Tension current [V]	Number of sessions [n]	Electrode location			Electrode size [cm ²]	
					Functions	A-tDCS	C-tDCS	A-tDCS	C-tDCS
AND	30	1	9	7	Memory	Fp1	O1	5×5	7×30
II	30–40	1–1.5				F7	F8		7×40
III	30–40	1–1.5			Emotions	Fp2	O2		

A-tDCS — anode electrode used during transcranial direct current stimulation; C-tDCS — cathode electrode used during transcranial direct current stimulation; Fp1 and Fp2 — frontal or prefrontal electrodes recording activity mainly from the frontal lobes of the brain; F7 and F8 — inferior frontal or anterior temporal electrodes recording activity mainly from the orbital, anterior temporal and lateral frontal regions of the brain; O1 and O2 — occipital electrodes recording activity mainly from the occipital lobes of the brain; Electrode locations: left hemisphere: Fp1, F7 and O1; Electrode locations: right hemisphere: Fp2, F8 and O2

year after the end of therapy. In the long-term assessment, statistical analysis was performed on 23 participants in the tDCS group (one person refused further cooperation, one died within a year of the end of the project) and 23 subjects in the sham tDCS group (one patient had a recurrent stroke, and one person withdrew from the project). After a month of direct current stimulation, there was a statistically and clinically significant improvement in all motor functions and in the emotional picture of the patients compared to sham procedures. The differences between the two groups regarding the functional state were the greatest for the WMFT test and amounted to as much as 51% ($p=0.04$) after a month, and even 57% ($p=0.02$) after a year, respectively. Also, in the case of improvement in reducing depression and anxiety assessed with the Hospital Anxiety and Depression Scale (HADS), the tDCS group showed an advantage, although slightly above the statistical significance limit ($p=0.06$ after a month of therapy; $p=0.07$ after a year from the end of the study). The Belgian authors of the above RCT study conclude that tDCS seems to be an effective complement to standard treatment. According to the researchers, the method allows for the consolidation of clinical effects and long-term improvement [45].

For the work by researchers from Belgium, patients with acute stroke and in the early period of post-stroke rehabilitation were recruited, while in the case of the dissertation, these were patients in the chronic period at the outpatient stage. This means that in terms of functionality, the participants of both projects were at different levels. In the case of BI, in the publication by Bornheim et al. [45], the comparison groups were homogeneous and defined as a “moderately severe” condition — 61.6 in the tDCS group and 64.4 points in the comparison group (no difference between groups with a p value of 0.63). In the case of the “stroke” group in the doctoral thesis, 68% of the population were in a “mild” condition (86–100 points) and 32% in a “moderately severe” condition — similarly to all participants in the study by the authors from the University of Liege.

The literature review also shows that transcranial direct current stimulation is effective in reducing anxiety episodes and treating depression not only in the stroke population.

Sampaio-Junior et al. [46] conducted a randomized, double-blind clinical trial involving patients with affective disorders in the form of recurrent unipolar depression. The study included 59 patients who were randomly assigned to one of two comparison groups — the first, where tDCS treatments (2 mA, 30 minutes) and the second, in which sham applications took place. All patients were also treated pharmacologically. The Hamilton Depression Rating Scale (HDRS) was used

to assess progress. After the completion of the therapy, a strong advantage of the method over the control group was found.

Various researchers also point to the possibility of using direct current stimulation in treating depression in teenagers and even small children. They present potential chances for creating reliable premises for treating Tourette syndrome and autism [3,4].

There are not many clinical reports on the above issues in the available literature. Interestingly, in contrast to the positive results obtained in the doctoral dissertation, there are both promising and critical publications in medical databases (PubMed, MEDLINE, Web of Science).

Guillouët et al. [47] in a 2020 multicenter double-blind RCT did not find any advantage of micropolarization (2 mA, 20 minutes) over standard speech therapy in stimulating short-term memory and frontal lobe activity. There was no significant intergroup difference ($p=0.47$) between the results regarding the number of verbs, adjectives, adverbs, pronouns used in patients’ speech, as well as the percentage of grammatical errors occurring in patients after ischemic stroke. However, French researchers indicate that further scientific projects should be conducted, which corresponds to the action resulting from the dissertation, because perhaps the right procedure is to combine speech therapy with tDCS procedures. Only such a “symbiosis” of the above methods is the most effective solution.

Similar conclusions are drawn from the publication by Miniussi et al. [48], who show the significant usefulness of transcranial direct current stimulation in cognitive reeducation and short-term memory restoration. The authors emphasize the importance of the problem and indicate that cognitive deficits are a common consequence of neurological diseases, especially traumatic brain injury, stroke and neurodegenerative disorders. There is evidence that specific cognitive training can be effective in cognitive rehabilitation. Several studies emphasize the fact that influencing cortical activity, through stimulation at the level of the cerebral cortex, can positively affect short-term cognitive performance and improve the rehabilitation potential of neurological patients. Modifications of brain activity can support cognitive functions such as memory and learning by facilitating local activity or by suppressing interfering activity from other brain areas [48].

A very interesting study was conducted by Wang et al. [49] in 2018, who decided to assess whether tDCS application affects short-term memory, as well as what is the optimal time of the procedure to obtain the best effects. Several different procedures were applied in the area of the dorsolateral prefrontal cortex (DLPFC) in healthy volunteers. After the project was completed, no improved performance in memorizing digits was noted

and no effect on short-term visual memory was found, regardless of the treatment methodology.

In turn, Lerud et al. [50] in their latest study from 2021 observed that the application of tDCS to the left supramarginal gyrus (SMG) in the parietal lobe affects selected elements of auditory memory and visual short-term memory depending on polarity. Cathodal stimulation was characterized by a negative effect, while anodal stimulation had a beneficial effect. These effects were shown to be significantly different from sham-tDCS stimulation, which had no effect on the results; they were also specific to the left hemisphere — no effect was found with cathodal stimulation in the right SMG — and were unique to pitch memory, in contrast to visual shape memory. The discussed results provide further evidence that the left SMG is a nodal point for auditory short-term memory and demonstrate the potential of tDCS to influence cognitive functioning. The authors recommend further programming of clinical trials involving real patients, and not only in the case of the healthy population.

It cannot be denied that the therapeutic mechanisms of transcutaneous direct current stimulation are not fully understood. Despite many works on this subject [27,51–53], experiments at the basic level — *in vitro*, animal experiments — still need to be conducted.

For example, Przeklasa-Muszyńska [54] presents — despite the lack of full knowledge in the literature of the mechanism of the effect of tDCS on the hypothalamic MU receptor — an interesting case report. The case report presents a study of a 58-year-old woman who was referred for a consultation to a pain clinic. As a result of a road accident, the patient suffered an injury (crushing) to her left lower leg, which required amputation. A few days after the procedure, phantom pain appeared. The sensation was recurrent, intensified in the evening and at night, with greater stress, sometimes there was a feeling of the foot “sliding out” of the leg (telescopic symptom). The intensity of the symptoms was 5–8 on the numerical rating scale (NRS). Another type of discomfort felt by the woman, which appeared after a few weeks, was a burning, tingling, 3–5 point intensity, constricting pain in the stump area. Pain relief was given in the form of ketoprofen, changed by the surgeon to celecoxib due to stomach pain, paracetamol 3–4 times a day, and tramadol 200 mg for exacerbation of phantom pain. The treatment was ineffective. The patient also started psychotherapy, physiotherapy based on exercises in front of a mirror, and relaxation. Lidocaine infusions were performed at a dose of 5 mg/kg. On the day of the infusion, the pain intensity decreased to 4 points. Due to dry mouth, palpitations, and poor health, amitriptyline was discontinued and citalopram 20 mg at night was added to the treatment. tDCS was suggested to the woman, a series of 10 treatments was performed

over 2 weeks. The anodal electrode (active) was located above the motor cortex (point C3), the cathodal electrode (inactive) was placed above the right eyebrow arch. Each stimulation lasted 20 minutes and the applied direct current was 2 mA. Only after the prescribed treatment was the remission of pain noted, although the exact mechanism of action on the pain center in the hypothalamus and the cerebral cortex has not been explained [54].

Implications for Nursing Practice

The growing body of evidence supporting the use of tDCS in patients with cognitive and emotional disorders after TBI and CVA has important implications for nursing practice, particularly in neurological, neurorehabilitation, and long-term care settings. Nurses play a key role in the identification and monitoring of cognitive and emotional deficits in patients after brain injury. Early recognition of memory impairment, emotional lability, depressive symptoms, anxiety, or reduced emotional regulation is essential for timely referral to multidisciplinary interventions, including tDCS-supported neurorehabilitation. Routine nursing assessments, combined with standardized screening tools, can facilitate appropriate patient selection and optimize therapeutic outcomes.

Also, nurses are central to the safe implementation and supervision of tDCS procedures. With appropriate training, nursing staff can participate in preparing patients for stimulation sessions, positioning electrodes according to established protocols, monitoring stimulation parameters, and observing patients for potential adverse effects such as skin irritation, headache, or transient discomfort. Given the favorable safety profile of tDCS, nurse-led monitoring enhances treatment adherence and ensures patient comfort and safety throughout the intervention. Moreover, nursing practice is crucial in patient education and therapeutic engagement. Nurses are often the primary source of information for patients and their families regarding the goals, course, and expected effects of tDCS therapy. Clear explanations about the non-invasive nature of the procedure, its role as an adjunct to standard rehabilitation, and the importance of regular attendance can reduce anxiety, increase acceptance of therapy, and improve compliance. Nurses contribute significantly to the integration of tDCS with comprehensive neurorehabilitation programs. Coordinating tDCS sessions with speech therapy, cognitive training, physiotherapy, and psychological support allows for a synergistic therapeutic effect. Nursing observations regarding patient motivation, fatigue, emotional responses, and functional changes provide valuable feedback to the interdisciplinary team and support individualized care planning.

Finally, the expanding use of tDCS highlights the need for advanced nursing competencies and continuing education in neuromodulation techniques. Incorporating basic knowledge of neuroplasticity, mechanisms of non-invasive brain stimulation, and evidence-based rehabilitation strategies into nursing education may enhance professional autonomy and strengthen the role of nurses in innovative neurorehabilitation models. Without a doubt, tDCS offers new opportunities for nursing practice by expanding the scope of supportive, patient-centered care in individuals with cognitive and emotional disorders after brain injury. Nurses are essential partners in assessment, safety monitoring, education, and interdisciplinary collaboration, contributing directly to improved rehabilitation outcomes and quality of life for this patient population.

Conclusions

Micropolarization tDCS treatments are a promising, non-invasive therapeutic method that can support the treatment of cognitive and emotional disorders in patients CVA and TBI. Due to its relatively low price, safety and ease of use, tDCS is an attractive alternative to pharmacotherapy and other neuromodulation methods, such as rTMS. Anodal stimulation (A-tDCS) increases the excitability of the cerebral cortex, while cathodal stimulation (C-tDCS) has an inhibitory effect, which allows for precise modulation of neuronal activity. The effects of the therapy can last from several minutes to up to 24 hours after the end of the session. Studies indicate a beneficial effect of tDCS in the treatment of depression, neuropathic pain and addictions, but methodological diversity and small sample sizes make it difficult to draw clear conclusions. tDCS has been shown to be an effective support in speech therapy rehabilitation of patients with aphasia and other neurological disorders, improving motor and emotional functions. Despite positive results, further clinical studies are needed to refine therapeutic protocols and determine the long-term effectiveness of this method.

tDCS opens up new directions of research on the therapy of cognitive and emotional disorders in patients after stroke and brain injury, but this area remains incompletely understood. Key research directions include optimizing stimulation protocols, including determining appropriate parameters of current intensity, electrode location and session duration, which can maximize the effectiveness of the therapy. Another significant challenge is to identify groups of patients who can benefit the most from tDCS, which requires further research on the mechanisms of neuroplasticity and individual differences in the response to stimulation. Future studies should focus on long-term monitoring of tDCS effects,


assessment of the durability of the obtained results and analysis of the combination of tDCS with other forms of rehabilitation, such as neurorehabilitation, speech therapy and cognitive training. An important aspect is also explaining the role of neurotransmitters and neuromodulators in the processes of neuronal plasticity induced by tDCS, which may lead to new strategies for the treatment of emotional and cognitive disorders. In the longer term, tDCS research may contribute to the development of personalized neurorehabilitation therapies, enabling the adjustment of stimulation parameters to the specific needs and clinical condition of the patient.

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