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MEDICAL BIOPHYSICS

On the Role of Priming in the Development of Modern Rehabilitation Technologies

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Abstract—Recent studies using priming, the effect of precedence, in the restoration of impaired functions and cognitive rehabilitation of neurological clinic patients have been analyzed. Various types of priming were considered, including transcranial magnetic and electrical stimulation, as well as the preliminary presentation of acoustic and visual stimuli. The presented data show that the range of conditions and specific types of successful application of priming in the clinic is quite wide, and the number of studies increases annually. It is believed that the activation of neuroplasticity mechanisms underlies the positive effects of priming in the treatment of many neurological and psychogenic disorders. Using the example of the author's own research, the advantages of visual priming in the form of resonance scanning and LED photostimulation with a gradually increasing frequency within the basic rhythms of the electroencephalogram are emphasized.

Keywords: non-invasive brain stimulation, restoration of impaired functions, cognitive rehabilitation, induction of neuroplasticity mechanisms, resonance scanning, EEG-guided adaptive neurostimulation

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Priming, the effect of precedence, is the use of preliminary noninvasive exposure, which modulates the effect of subsequent stimulation through the mechanisms of excitability and neuroplasticity. The same or another brain stimulation protocol can act as priming, as well as any type of activity, cognitive load, physical exercises, etc. [1]. The use of various priming options is based on the concept of metaplasticity, according to which the threshold for the induction of neuroplastic changes is dynamic and significantly depends on previous activity [2, 3].

A significant impact of priming on the effects of noninvasive brain stimulation has been demonstrated mainly in numerous studies on healthy people [4–6]. However, in recent years, priming effects have been actively used in the restoration of impaired functions and cognitive rehabilitation of neurological clinic patients. The purpose of this study is to analyze recent publications and identify prospects for further development of this direction of clinical research.

Judging by the literature data, transcranial magnetic and electrical exposures are most actively used as priming. It has been shown that preliminary rhythmic transcranial magnetic stimulation with the frequency of the alpha rhythm of the electroencephalogram (EEG) had a specific neuromodulating effect in just one session in patients with drug-resistant depression [7]. Successful induction of nervous excitability and neuroplasticity was achieved by combining transcranial electrical stimulation with alternating current and transcranial magnetic stimulation [8], as well as with preliminary exposure to rhythmic transcranial magnetic stimulation with theta flashes [9].

Priming in the form of transcranial direct current electrical stimulation caused long-term plasticity similar to potentiation; this led to the restoration of impaired synaptic plasticity in patients with mental disorders, including depression and schizophrenia [10]. In the treatment of autism spectrum disorders, traumatic brain injuries, Alzheimer's disease, and diabetes, the use of priming in the form of preliminary presentation of rhythmic transcranial magnetic stimulation with the frequency of theta EEG rhythm has proven effective [11]. Periodic effects of transcranial magnetic stimulation with theta flashes, which increase the susceptibility of the brain to subsequent stimulation, have also been successful in restoring motor functions after a stroke [12]. The authors believe that such priming creates a state of increased excitability, which allows the use of treatment methods that induce neuroplasticity and restoration of motor skills.

Acoustic priming can be effectively used as a means of inducing plasticity to restore functions after various injuries and traumas. To this end, combinations of loud sound with transcranial magnetic stimulation were successfully used, which caused long-term changes in the connections between the cortex and the

Table 1. The dynamics of development of noninvasive rehabilitation technologies using priming

The purpose/condition of the study	Type of priming	The presented stimuli	Reference
Treatment of neurological diseases	Transcranial electrical stimulation with alternating current	Electrical/magnetic stimulation	Goldsworthy et al., 2016 [7]
Treatment of neurological diseases	Transcranial magnetic stimulation by theta flashes	Rhythmic magnetic stimulation with a frequency of 3–5 Hz	Hordacre et al., 2017 [8]
Correction of learning and memory in schizophrenia	Sensory tetanization	Rapidly repetitive auditory or visual stimuli	Sanders et al., 2018 [17]
Treatment of depression	Transcranial magnetic stimulation	Rhythmic magnetic stimulation with a frequency of 8–13 Hz	Zrenner et al., 2020 [9]
Migraine treatment	Visual priming	Short series of rhythmic light pulses of different frequencies	Perenboom et al., 2020 [18]
Treatment of motor disorders	Acoustic priming	Loud acoustic signals	Germann, Baker, 2021 [14]
Treatment of mental disorders	Transcranial direct current electrical stimulation	Electrical + rhythmic light stimuli	Frase et al., 2021 [10]
Recovery of motor functions after stroke	Transcranial magnetic stimulation by theta flashes	Rhythmic magnetic stimulation with a frequency of 3–5 Hz	Zhang et al., 2022 [12]
Diagnosis of autism	Visual priming	Vertical/horizontal grids	Cherenkova, Sokolova, 2022 [16]
Determination of the maturity of cortical rhythmics in schoolchildren	Resonance scanning	Photostimulation with a step-by-step increasing frequency from 5 to 15 Hz	Savchuk et al., 2022 [19]
Correction of stress-induced states	Resonance scanning as visual priming	Photostimulation with step-by-step increasing frequency	Fedotchev et al., 2023 [20]
Treatment of Alzheimer's disease	Acoustic priming	40 Hz loud tone + transcranial electrical stimulation with alternating current	Liu et al., 2023 [15]
Treatment of neurological and psychiatric diseases	Transcranial magnetic stimulation by theta flashes	Rhythmic magnetic stimulation with a frequency of 3–5 Hz	Jannati et al., 2023 [11]
Motor rehabilitation	Acoustic priming	Audible clicks + electrical stimulation	Germann et al., 2023 [13]
Cognitive rehabilitation of university students	Resonance scanning as visual priming	Photostimulation with step-by-step increasing frequency	Polevaya et al., 2023 [21]
Optimization of visual priming parameters	Resonance scanning as visual priming	Photostimulation with step-by-step increasing frequency	Fedotchev et al., 2023 [22]

brainstem [13]. This approach was implemented by the authors in a wearable device combining loud acoustic signals with biceps muscle stimulation and is intended for use in everyday life by patients with disorders of the reticulospinal tract [14]. It has also been shown that acoustic priming (40 Hz tone) in combination with transcranial electrical stimulation with alternating current led to improved cognitive functions in patients with Alzheimer's disease [15].

Visual priming was used in a recent study to identify the characteristics of children with autism spectrum disorders [16]. Healthy and sick children were presented with targeted stimuli in the form of grids consisting of horizontal and vertical lines, and the prime was vertical grids, presented with a slight advance. It was shown that in comparison with normally developing children, the temporal nature of the interaction of prime with target stimuli changed in children with autism spectrum disorders.

In order to induce neuroplasticity, a technique of sensory tetanization was proposed, which consisted in presenting a sequence of rapidly repeating auditory and visual stimuli [17]. It was assumed that such priming could serve as a diagnostic and therapeutic tool in a clinical setting. To identify the dynamic features of the sensitivity of the visual cortex in migraine, visual priming ("chirp" stimulation) was successfully used in the form of exposure to short series of rhythmic light pulses in a wide frequency range [18]. It was found that an enhanced reaction to such effects was observed 48 h before the onset of a migraine attack, but the optimal frequency of the use of visual priming in the treatment of migraine has yet to be established.

Earlier in our research that was aimed to assess the maturity of cortical rhythmics in younger schoolchildren, a resonance scanning technique was used, consisting in the analysis of EEG with LED photostimulation and a gradually increasing frequency within the main EEG rhythms [19]. It has been shown that scanning "highlighted" by the resonance with the fine structure of the individual EEG spectrum identified potential resonantly active brain oscillators and could serve as a technique for stimulating the mechanisms of neuroplasticity and increasing the susceptibility of the brain to subsequent stimulation. These data suggested that resonance scanning can be successfully used as visual priming during procedures for suppressing exam stress and cognitive rehabilitation of university students using EEG-guided adaptive neurostimulation with feedback [20]. This assumption was confirmed in strictly controlled studies, where it was shown that only under the conditions of preliminary resonance scanning, significant positive shifts in cognitive functions and indicators of functional state, as well as a decrease in stress levels, were recorded in students [21]. The prospects of the proposed approach were evidenced by the fact that by optimizing the parameters of preliminary resonance scanning, increased effectiveness of therapeutic effects could be achieved [22].

Thus, the reviewed data show that the range of conditions for the successful application of priming in the clinic is wide, as well as its specific characteristics (Table 1). It should be noted that the number of studies has been exponentially increasing in recent years, which indicates the prospects of this direction of research.

In conclusion, it is important to emphasize that the considered examples demonstrate the important role of priming in the development of modern rehabilitation technologies. Judging by the chronology of publications, this role increases over time. Along with magnetic and electrical exposures, wide clinical prospects are opening up in connection with the use of acoustic and visual priming. It seems promising to use resonance scanning as a priming due to its advantages such as dynamism, software-controlled digital stimulation parameters and the possibility of involving the central regulatory mechanisms of the brain in the therapeutic process.

ABBREVIATIONS AND NOTATION

EEG electroencephalogram

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This work does not contain any studies involving human and animal subjects.

CONFLICT OF INTEREST

The author of this work declares that he has no conflicts of interest.

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