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Current knowledge on selected rehabilitative methods used in post-stroke recovery

Aktualny stan wiedzy o wybranych metodach rehabilitacji chorych po udarach mózgu

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Key words
motor imagery, constraint induced movement therapy, mirror therapy, stroke

Abstract
Understanding brain plasticity after stroke is important in developing rehabilitation strategies. Active movement therapies show considerable promise but their individual application is still not fully implemented. Among the analysed, available therapeutic modalities, some became widely used in therapeutic practice. Thus, we selected three relatively new methods, i.e. mirror therapy, motor imagery and constraint-induced movement therapy (CIMT). Mirror therapy was initially used in the treatment of phantom pain in patients with amputated limbs and later, in stroke patients. Motor imagery is widely used in sport to improve performance, which raises the possibility of applying it both as a rehabilitative method and in accessing the motor network independently of recovery. Whereas CIMT is based on the paradigm that impairment of arm function is exacerbated by learned non-use and that this, in turn, leads to loss of cortical representation in the upper limb.

Słowa kluczowe
wyobrażeniowy trening planowania ruchu, terapia ograniczania i wymuszania ruchu, terapia lustrzana

Streszczenie
Zrozumienie zmian określanych mianem plastyczności mózgu jest ważne w celu opracowania odpowiednich strategii rehabilitacji. Terapie oparte na ruchach czynnych wykazały obiecujące znaczenie lecz indywidualne ich zastosowanie nie zostało w pełni wdrożone. Pośród dostępnych metod terapeutycznych, które zostały poddane analizie, niektóre stały się powszechnie stosowane w praktyce klinicznej. W celu realizacji tego artykułu wybrano zatem trzy metody, które są stosunkowo nowe, tj. terapię lustrzaną, wyobrażeniowy trening planowania ruchu i terapię ograniczania i wymuszania ruchu. Terapia lustrzana była początkowo wykorzystywana do leczenia bólów fantomowych u osób po amputacjach kończyn, dopiero później wypróbowano jej działanie u chorych po udarach mózgu. Wyobrażeniowy trening planowania ruchu jest często stosowany w sporcie w celu poprawy osiągnięć co pozwala również na jego zastosowanie jako metody rehabilitacyjnej. Terapia ograniczania i wymuszania ruchu opiera się natomiast na teorii, która mówi, że zaburzenia funkcji kończyny górnej u osób po udarze mózgu są spotęgowane przez wyuczone nieużywanie kończyny górnej, prowadzące do fizycznych zmian w korowej reprezentacji kończyny w pierwotnej korze czuciowej.

The individual division of this paper was as follows: a – research work project; B – data col-lection; C – statistical analysis; D – data interpretation; E – manuscript compilation; F – publication search

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INTRODUCTION

The main problem faced by approximately 69% of people after stroke is the lack of functionality of hemiparetic limbs[1]. Although a large cohort of rehabilitated patients is able to perform simple movements, e.g. flexion and extension, their use in everyday life is difficult. This is because the central nervous system (CNS) is not able to induce trained muscle synergies and coordinate the execution of more complex movements that are necessary in the management of activities of daily living – ADL, such as getting dressed or eating. This is particularly evident in people with upper limb disabilities, where more than half of patients present a motor deficit that persists for many months or even years, significantly reducing ADL. Therefore, the improvement of arm function is a very important element of rehabilitation.

Rehabilitation of a patient after stroke often entails several different interventions and generally requires (if possible) cooperation between the patient, care-givers and the rehabilitation team. In addition, it is important that the introduction of appropriate therapy takes place during the period of greatest effectiveness for a given method. For example, the use of eye-hand coordination exercises (e.g. virtual therapy) during the acute phase (<1st month) or in the chronic phase (>6th month) will not produce as good results as in patients within the 3-6 month period[2,3]. It should also be remembered that not all movement disorders are closely related to the choice of a physiotherapeutic method. Many patients may use surgical interventions, pharmacology or orthopaedic prosthetics to reduce motor impairment. For example, permanent pain can significantly affect motivation and willingness to participate in rehabilitation treatments[4]. Therefore, when planning an individual therapeutic programme for these patients, all co-morbidities should be considered within the selected therapeutic method.

This article describes three methods that are relatively new and widely used in clinical practice to face the complexity of individual rehabilitation treatments.

MIRROR THERAPY

Mirror therapy or mirror visual feedback is one of the method based on neuroscience. Mirror therapy was developed in the nineties by the American behavioural neuroscientist Vilayanur Ramachandran (University of California, San Diego)[5-8]. It was initially used to reduce phantom pain after limb amputation[5] and later in patients after stroke[9].

Mirror therapy is based on triggering feedback by transmitting visual information. It was found that the mechanism of its action is related to the activity of mirror neurons[10]. Activation of mirror visual feedback (MVF) stimulates mirror neurons in the contralesional hemisphere of the brain. As a result, the body perception pattern is modified in a patient with an amputated or affected limb[11-13]. The vastly dispersed mirror neuron system, located in the cortex, was accidentally discovered at the beginning of the nineties[14]. Its complex role is explained by Rizzolatti and Sinigaglia[15], mainly involving observation of movement activity/action and its meaning. Information coming from this observation is sequentially transmitted to the brain's motor area. In order to stimulate and activate the mirror neuron system, one should observe a full movement activity/action, and not only individual, selected movements of the given activity (even if they are a component of many different activities). It is important to understand the purpose of the activity[15]. An equally important feature of the mirror neuron system is imitation by performing/repeating the previously observed movement, with a full understanding of two key elements: "what" movement is performed and "why" it is performed[15]. The function of the complex mechanism of mirror neurons can be observed in neuroimaging (e.g. fMRI – functional magnetic resonance imaging, PET – positron emission tomography, etc.)[14]. Observation of movements, which is one of its main principles, leads to stimulation and subsequent consolidation of changes in the motor system of the brain. The patient independently performs the exercise after its previous observation and understanding, and without active support of the therapist[16]. During the mirror therapy session, the illusion of the existence of an undisturbed, healthy body pattern is evoked. After limb amputation, the patient watching the reflection of the opposite, non-amputated limb in the mirror, "cheat the brain" and deliberately introduce misleading information about the existence of the limb[17]. Patients with stroke, on the other hand, give feedback to the brain about the existence of a fully functional, non-affected limb[7].

At the beginning of mirror therapy, the patient should be familiarized with its goals and procedure. Before each treatment, the intensity of pain should be assessed. The number of sessions and the way they are treated are always selected individually and tailored to the needs of each patient. Mirror therapy is carried out daily, individually with each patient in isolated rooms for about 15-30 minutes and with an unlimited number of sessions[17]. During the session, the patient focuses on the reflection of the non-affected limb in the mirror and performs active movements. S/he can also simulate everyday activities in front of the mirror. Each therapist who uses mirror therapy, modifies and leads it in an individual way depending on his/her own experience. It is extremely important to start mirror therapy as soon as possible, within the first days of post-stroke rehabilitation.

The importance of mirror therapy and its usefulness in the treatment of patients after stroke has been confirmed by research based on fMRI[18,19]. Michielsen et al.[18], investigating stroke patients using fMRI, noted that cerebral cortex stimulation occurs when the patient performs simultaneous movements with both limbs during the session of mirror therapy (simultaneously, the healthy limb observed in the mirror and the affected one, hidden behind the mirror). The efficacy of mirror therapy was found in the treatment of patients following limb amputations[17], stroke[20], Complex Regional Pain Syndrome type I (CRPS type I), full rupture of the brachial plexus and spinal cord injury. It has been shown that mirror therapy is more effective than conventional treatments for chronic pain and paralysis resulting from stroke[21]. According to Thieme, mirror therapy can be used to improve motor function after stroke, improve the quality of ADL, reduce pain and weaken the effect of visuo-spatial neglect. Thieme et al.[22] compared 14 studies on the effects of mirror therapy among a total of 567 patients. They confirmed the significant effect of mirror therapy on the recovery of motor function in stroke patients (effects maintained after 6 months), improvement in everyday life and pain reduction. However, it was noted that visuo-spatial neglect did not improve coherently. Yun et al.[23] conducted a study on a group of 60 patients with hemiplegia after stroke. In the first of three subgroups, they used Neuromuscular Electrical Stimulation (NMES) in combination with mirror therapy, in the second only NMES, and in the third, only mirror therapy. The best effects of therapy were achieved in the mixed subgroup. In turn, Kim and Shim[24], after examining 14 stroke patients with hemiplegia of the upper limb, noted significant improvement in the manipulative function in those subjected to mirror therapy. Also, Invernizzi et al.[25] indicate the important positive result of mirror therapy combined with classical rehabilitation in patients after light stroke with paralysis of the upper limbs.

Currently, modifications of mirror therapy are also used, such as virtual mirror therapy with the use of three-dimensionality (3D)[26].

MOTOR IMAGERY TRAINING

Simulation of motor activities has its origin in psychology and in the field of motor sciences. Already in 1825, the German psychologist Johann Friedrich Herbart described movement as a perceptual effect and stated that a motor imagery, being a perceptual effect, can trigger specific movement[27]. Currently, scientists within fields of cognitive psychology, cognitive robotics or sport psychology provide a lot of information about so-called “basic action concepts” for motor control[28]. These reports suggest that the structures of mental representation of complex movement change along with the acquisition of skills. This means that the structures of mental representation of complex motion can, by means of appropriate motion tasks, develop to the functional level by modifying the intermediate structures associated with the basic concept of action[27,29]. The first scientific studies using structures of mental representation pointed to performance improvement after the use of imaginary tasks. Describing the process of imagining, it should be noted that it refers to a set of skills such as visual imagery, kinesthetic imagery, motor imagery or their combination.

Motor imagery is a cognitive skill widely used in the training of athletes to optimize specific motor tasks. It is also implemented in neurological rehabilitation and cognitive psychology. Motor imagery is defined as a state of dynamic mental action that simulates movement without its performance. Many authors reported that motor imagery training can improve motor skills, however, its efficacy depends on the individual imaginative abilities[30]. Currently, this method is being used in the rehabilitation of patients with motor deficits caused by various neurological diseases such as multiple sclerosis, cerebral palsy or stroke. It has also been included in the complex paradigm of pain treatment, called graded motor imagery (GMI), which is composed of three main actions i.e. visualization, recognition of the right and left limb images and mirror therapy[31].

Motor imagery training focuses on improving the process of planning motor activities in their cognitive aspect through imagining the proper motor task. Motor imagery training is based on simulated motor activity through a cognitive process. During training, the same areas of the brain are activated (depending on the motor activity, these are the lower areas of the temporal cortex, premotor cortex and supplementary motor cortex), which are activated during physical movement. Training usually takes place in an isolated room, and therapeutic sessions last from 10 to 60 minutes. The patient initially receives information about a specific motor task in the form of illustrations or videos, and is then asked to replicate them in imaginative form. To obtain significant improvement, motor imagery training is carried out for a minimum of 2 weeks but does not usually exceed 6 weeks. Neurophysiological studies using functional magnetic resonance imaging (fMRI) and transcranial magnetic stimulation (TMS) revealed that brain activity during motion imagery training is similar to the activity observed during real motion[32-34]. In clinical trials, activity of such areas as the supplementary motor area, premotor cortex and cortices in the parietal area were observed. Activity during motor imagery training was also observed in the primary somatosensory cortex S1 despite lack of contact with the physical object[29]. These results suggest that not only the brain areas associated with motor skills play an important role in the process of movement visualization, but also the sensory ones[27].

In a clinical study using TMS and fMRI, Mizuguchi et al.[35] noticed a significant increase in brain activity among patients who had a specific object placed in their hand during motor imagery training. The authors point to the connection between the sensory and motor areas of the brain, suggesting an increase in the quality of motor imagery training by providing sensory feedback[35].

In order to explain the imaginative effect of motor imagery training, different theories of scientific models have been proposed, which demarcate the obtained effect into two types: physiological, (i.e. neuromuscular), and central (i.e. associated with modelling of the nervous system). It has been assumed that motor imagery training is based on simulation processes engaging the brain’s motor areas to pass the images obtained or the movement performed between the neuronal correlates. In addition, research has shown that training induces increased concentration and attention to motor processes. Many neuroimaging studies also report a link between motor imagery and the activation of specific neuronal circuits (consisting of an additional motor area, premotor cortex, parietal lobe, basal ganglia and cerebellum) that are involved in the early phase of motor programming[36,37]. However, in patients with CNS injury, the ability to perform requested mental tasks should be taken into evaluation and consideration, because both the size of a lesion area and its location can significantly affect the correctness of the performed task. For example, the lesioned parietal lobe which is associated with the production of the kinaesthetic model may reduce the accuracy of the imagined movement[29].

Despite presented limitations, motor imagery training can be considered as a great tool that can be used both in clinical and home setting, for people after stroke. Evidence suggests that in healthy people, this type of training activates neural networks, providing some benefits in training athletes. However, in patients after stroke, this information is still unclear, and mechanisms that occur during therapy are not fully explained. There are no specific recommendations, such as the intensity of training. So far, the adverse events and limitations in the use of this therapeutic method have not been described. Regarding stroke, this concept is open and requires further research.

CONSTRAINT-INDUCED MOVEMENT THERAPY

One of the effective and promising upper limb therapy treatments after stroke, which has been devoted a lot of research, is the method of Constraint-Induced Movement Therapy (CIMT) developed by Taub[38]. This method consists in immobilizing the non-affected arm to activate movements in the hemiparetic one. The non-affected limb is placed in a glove or sling, which limits its use. The massed practice is applied to the hemiparetic upper limb with positive biofeedback award. To improve hand function, the shaping technique and shaping behaviour are used[39]. The difficulty of tasks for the affected hand increases gradually, so that the patient has the feeling of using it effectively. Success is rewarded with positive feedback. This therapeutic approach reduces and prevents the occurrence of the learned non-use phenomenon. CIMT is based on the theory that the abnormalities in hand and arm function among people after stroke are heightened by the learned non-use of the upper limb, which leads to physical changes in the cortical representation of the limb in the primary sensory cortex[40]. Learned non-use can be developed in the early post-stroke period, when the patient, due to the difficulty in using the paretic limb, compensates by increasing dependence on the non-affected limb. It was found that this compensation makes it difficult to restore function in an inferior limb[41]. The condition for application of this method is the possibility to begin in the position – forearm pronation, flexion of the wrist joint and at least 10 degree active extension in the metacarpophalangeal and interphalangeal joints, and at least 20 degrees in the wrist joint[42].

Initially, the original CIMT method was based on training lasting 6-8 hours per day and immobilizing the non-affected limb for 90% of the time during the day[43,44]. In later protocols, CIMT modifications were also used, e.g. mCIMT consisting in restriction of non-affacted limb movements and paretic limb exercises lasting less than 3 hours, or Force Used (FU), in which non-affected limb movements were restricted without specific training of the paretic limb[45-47]. Comparison of six- and three-hour CIMT training in 15 rehabilitated post-stroke patients showed significant improvement in motor function (Wolf Motor Function Test) and increased use of the paretic arm (Motor Activity Log). However, the effect was greater in people exercising intensively, i.e. for 6 hours[48].

Many previous studies have assessed the impact of CIMT mainly on arm and hand function, motor impairment and ADL, while the number of studies evaluating the effects with neurophysiological methods is much smaller[47]. Studies using neurophysiological methods such as fMRI, PET and TMS indicate the reorganization of the brain under the influence of exercises performed using the CIMT method[47]. The results of neurophysiological research are not consistent regarding whether reorganization occurs to a greater extent in the damaged or undamaged hemisphere[49], nor has the pattern been established according to which the brain is reorganized under the influence of exercises. Sceptical voices in the discussion on plasticity changes occurring in the brain under the influence of CIMT suggest that they are rather the result of adaptation and compensation strategies rather than actual reorganization and repair[50].

Using TMS and fMRI, Liepert et al.[51] indicate that after stroke, but before CIMT therapy, patients lack intracortical inhibition (ICI). After CIMT, ICI changes were more expressed in the lesional than contralesional hemisphere, but could result in both an increase and decrease in ICI. In three patients, fMRI results showed that after CIMT, cortical activity was lower when compared to activity before CIMT. At the same time, ICI decreased after therapy. CIMT induces changes by promoting intracortex excitability, mainly in the affected hemisphere. After 2 weeks of treatment, the patients achieved significant improvement in motor activity according to the Motor Activity Log (MAL) and, at the same time, the cortical representation of the paretic hand muscles significantly increased, whereas this area of the intact hemisphere was insignificantly reduced. After 6 months, the improvement of function persisted. Kim et al.[52] observed improvement in motor function of an affected limb after 2 weeks of CIMT after stroke. In three patients after treatment, new activation of contralateral motor and premotor cortex was found. In the 4th of them, ipsilateral activation of the motor cortex and supplementary motor area (SMA) were found. Gauthier et al.[53] noted that the structural changes taking place in the brain after CIMT therapy are directly proportional to the clinical improvement. These authors compared the effects of CIMT and control therapy by using structural MRI. In the CIMT group, they found an increase of grey matter in the motor and sensory areas, both contralaterally and ipsilaterally to the paretic arm, bilaterally and symmetrically, and bilaterally in the hippocampus. The observed increase of grey matter was correlated with the improvement of the limb used in the real world. In the control group, there was no increase of the grey matter.

In the study by Zhao et al.[54], effectiveness of 3-week CIMT therapy was evaluated in 15 patients after stroke. The upper limb function was assessed with the Wolf Motor Function Test (WFMT), the activities of daily living were assessed with MAL, whereas the brain reorganisation was analysed by the use of fMRI scans. After therapy, they observed a significant improvement in the WFMT and MAL tests, and a significant reduction in the time of performing the activities. The volume of the active cortex area increased after treatment. In addition to reducing the activity around the lesioned area, new areas of brain activities were found including: the supplementary motor area, the premotor area and the ipsilateral sensory-motor area. The authors concluded that CIMT significantly improves motor function and daily use of the upper limb in stroke patients, and promotes cerebral and functional reorganization.

Lin et al.[55] showed a significant increase of brain activity in both hemispheres after CIMT treatment. This activity was especially actuated in the contralesional hemisphere, during movements of both non-affected and affected limbs. In the control group, there was a decrease of brain activity within the primary sensory-motor cortex in the ipsilesional hemisphere during exercises performed by the affected hand. After using CIMT and a traditional rehabilitative method in the control group, among patients within 2 weeks after stroke, Boake et al.[56] argued that motor improvement during the first three months after stroke is associated with increased stimulation of the affected hemisphere. Wittenberg et al.[57] conducted CIMT therapy and used a traditional method in the control group in patients being more than one year since stroke onset. The results of the WMFT and Assessment of Motor and Process Skills (AMPS) did not differ between the groups. Brain activity during the motor task significantly decreased, and the size of the motor maps increased in the ipsilesional motor cortex.

Könönen et al.[58] evaluated the effects of CIMT with fMRI and TMS in 11 patients in the long-term clinical follow-up after stroke. After intensive CIMT rehabilitation, changes in sensory-motor cortical activity (fMRI) and cortico-spinal conduction were observed. Activation and functional changes observed in fMRI and TMS analysis significantly correlated with the degree of clinical improvement in hand motor behaviour. In this study, patients with severe deficit in hand function prior to therapy achieved greater improvement in function than those entering treatment with a mild deficit. Despite the fact that the injured hemisphere was different in these patients, the authors found a consistent (ipsilesional) increase in activity in regional fMRI and these changes in fMRI strongly correlated with improved motor behaviour as well as increased corticospinal conduction (velocity). The authors concluded that CIMT is clinically useful and beneficial even in a group of diverse patients during the long-term follow-up and that clinical improvement correlates with changes in functional imaging parameters.

Hamzei et al.[59] distinguished two different brain reorganization patterns after CIMT therapy by using fMRI and TMS assessment. In patients with intact hand area in the primary cortex (M1) and its descending motor fibres (these patients had proper motor evoked potentials [MEP]), a reduction in primary sensory-motor cortex (SMC) was observed on the side of the lesion (ipsilesional), which was parallel to the increase in intracortex excitability. This pattern presumably reflects an increase in synaptic efficiency. If M1 or its descending pyramidal pathway is damaged (MEP from the paretic hand is pathological), the SMC activity on the ipsilesional side increases and is accompanied by a reduction in intracortex excitability. The authors of this report hypothesised that in the given situation, it is not possible to increase synaptic efficiency leading to reorganization with the extension, displacement and recruitment of additional cortical areas within the sensorimotor network.

Results regarding the meta-analysis of studies evaluating the effects of upper limb therapy in patients after stroke using fMRI and TMS indicate neuronal changes in the sensory-motor cortex of the ipsilesional hemisphere, which is accompanied by affected limb motor improvement under the influence of targeted rehabilitation[60].

Sawaki et al.[61] compared the effects of CIMT therapy using TMS and WMFT in patients up to 9 months after stroke and over a period of 12 months. The short-term follow up showed better results in WMFT than in the group subjected to long-term follow up. In the long-term follow-up group, there was larger cortical reorganization associated with a greater, posterior shift in the position of motor maps and a more accentuated increase in the size of these maps.

Conducted systematic reviews and meta-analyses regarding CIMT effectiveness are promising and indicate moderate-quality evidence concerning the positive effect of CIMT on the function of paretic upper limb function, motor impairment and lower-quality evidence regarding the beneficial effect of CIMT on the performance of ADL[4,45]. Only the latest review of the Cochrane Database indicates that the impact of CIMT on disability is not as obvious as previously thought[47]. The authors of these studies particularly emphasize the success of CIMT in improving the use the affected limb in everyday situations[44,47,49]. Individuals subjected to CIMT presented improvement in motor function, in the amount of use and quality of motion in the inferior limb and transfer of skills from the clinic to activities performed in the real world such as at home or the social environment of the patient[44,49].

SUMMARY

The methods of rehabilitation described in the article can be classified as those that do not require high financial outlay and can also be carried out (after appropriate training) at home. Opinions on these methods indicate that each of them can be adapted to the individual needs of a patient, which includes the possibility of creating a kind of sub-category for the methods related to the intensity of tasks performed. Many authors draw attention to the direct relationship between intensive training and the reconstruction of motor function[4,36]. This situation confirms the complexity of the entire treatment process, which is a challenge associated with the identification of the best individual treatment method. Recovery of lost (e.g. as a result of stroke) motor skills is possible due to feedback provided from the environment and is also dependent on the amount and frequency of exercises[62].

In mirror therapy, motor imagery training and constraint-induced movement therapy, we deal with reinforced feedback (visual, sensory) and intensive training (both mental and motor). The analysed scientific studies report that motor learning is more effective when requested exercises are divided by periods of rest between repetitions (distributed practice) in comparison to the situation when repetitions are performed in one training block (massed practice)[63]. Despite the fatigue process, it turned out that the efficiency during training increases in a linear way thanks to the breaks between exercises. The introduction of variable tasks (i.e. variable practice) improves memorizing their performance synergy in relation to the tasks that are always executed in the same way (constant practice)[64]. In addition, it is important that exercises are selected in a random manner (random practice), which leads to better performance of each of these tasks than when only one task is practiced[65].

Reports from scientific literature confirm the importance of the described methods for post-stroke rehabilitation, pointing to their effectiveness[4]. However, it does not provide an unambiguous answer regarding the optimal frequency of exercises that should be used. In general, the available data is of poor quality and is not very helpful in adopting specific clinical decisions. Nevertheless, the available data indicate potential improvement, with the relatively high frequency of repetitive tasks, both for mirror training, motor imagery and constraint-induced movement therapy. Therefore, the described methods should be dedicated to patients after stroke.

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