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Mirror therapy in neurological rehabilitation

Terapia în oglindă în recuperarea neurologică

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Abstract

Neurological rehabilitation is a continuously developing area, involving patients with a degree of disability secondary to a nervous system disorder. Recently, a neurological rehabilitation technique has been innovated, mirror therapy, designed to influence neuroplasticity using an optical illusion.

This study aims to illustrate the positive effect of this therapy in neurological patients, adults and children, and to promote this modern therapeutic concept.

Using neurological rehabilitation, mirror neurons, mirror therapy as key words, the PubMed database was searched for studies monitoring the effects of this therapy in neurological patients.

The analyzed studies demonstrated the role of mirror therapy in improving phantom limb pain, in reducing bradykinesia in Parkinson's disease, as well as in accelerating motor recovery in stroke survivors. Hypotheses regarding the implication of mirror neurons in autism were also launched.

In conclusion, the mirror neuron network, the cellular substrate of this therapy, has an impressive potential to provide solutions for neurological rehabilitation.

Keywords: neurological rehabilitation, mirror neurons, mirror therapy.

Rezumat

Reabilitarea neurologică este o disciplină în continuă dezvoltare, adresată pacienţilor cu un grad de invaliditate secundar unei afecţiuni a sistemului nervos. Recent, a fost inovată o tehnică de reabilitare neurologică, terapia în oglindă, concepută să influenţeze neuroplasticitatea apelând la o iluzie optică.

Lucrarea îşi propune să ilustreze efectul pozitiv al acestei terapii la pacienţii neurologici, adulţi şi copii, şi să promoveze acest concept terapeutic modern.

Cu cuvintele cheie - reabilitare neurologică, neuroni oglindă, terapia în oglindă - au fost căutate în baza de date PubMed studii care au urmărit efectele terapiei la pacienţii neurologici.

Studiile analizate au demonstrat rolul terapiei în oglindă în ameliorarea durerii membrului fantomă, în reducerea bradikineziei din boala Parkinson, dar şi în accelerarea recuperării motorii la pacienţii supravieţuitori unui accident vascular cerebral. Au fost lansate, de asemenea, ipoteze cu privire la implicarea neuronilor oglindă în autism.

În concluzie, reţeaua neuronilor în oglindă, substratul celular al acestei terapii, prezintă un potenţial impresionant de a oferi soluţii în recuperarea neurologică.

Cuvinte cheie: reabilitare neurologică, neuroni oglindă, terapia în oglindă.

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Introduction

Neurological rehabilitation is a continuously developing area, with a major impact on the increase of the quality of life of patients with a degree of disability secondary to a nervous system disorder. With the revolutionary discovery of mirror neurons, researchers in this field have provided neurophysiological evidence of their role in the acquisition of knowledge (language, gestures), in empathy, as well as in the recovery of diminished or lost sensory and motor functions. Recently, a neurological rehabilitation technique termed mirror therapy has been innovated, which was designed to activate the mirror neuron network using an optical illusion, and thus to influence neuroplasticity in a non-invasive manner.

Researchers in the field of neurophysiology and neurological rehabilitation have focused their attention on the beneficial effects of mirror therapy in adult and pediatric patients with disabilities secondary to neurological disorders, promoting this modern therapeutic concept as an effective, inexpensive, well-tolerated tool that can be applied at home, with a scientifically proven clinical effect.

Patients with various neurological disorders – sequelae after stroke or trauma/surgery, Parkinson's disease, phantom limb pain, complex regional pain syndrome – were included in numerous clinical trials, and changes occurring in symptomatology, the recovery of sensory and motor deficits, the increase of autonomy and the improvement of the quality of life were monitored following application of mirror therapy along with classical rehabilitation methods.

It has been demonstrated that this therapy had a positive impact in improving phantom limb pain, in reducing bradykinesia in Parkinson's disease, in rehabilitating stroke survivors. For patients with stroke, studies performed so far have shown the effectiveness of mirror therapy in increasing muscle strength in paretic upper and lower limbs, improving joint mobility, ameliorating coordination, balance and gait, and increasing the degree of autonomy in daily activities. Literature data suggest that mirror neurons will probably prove to be the etiology, as well as the key of the treatment of disorders such as autism.

Mirror neurons

Mirror neurons are, according to the neuroscientist Ramachandran, "neurons that shaped civilization". Some authors consider that these neurons represent a genetic adaptation meant to fulfill a socio-cognitive function, with a decisive role in the development of interhuman relations (Cook et al., 2013).

Mirror neurons were discovered two decades ago in the brain of macaque monkeys, initially in area F4 of the premotor cortex and subsequently in the parietal lobe (Oztop et al., 2013). At that time, it was believed that their only role in monkeys was to recognize some observed actions. Later research has shown a much more complex function: their implication in understanding actions, intentions and in imitation has been demonstrated, hence their name of "mirror" neurons. Thus, it was concluded that these are visual and motor neurons at the same time (Rizzolatti, 2005; Cinteză, 2012).

Studies in this direction, being non-invasive, were also applied to humans; neuroscientists have shown that when a human subject observes an action performed by another subject, their motor cortex becomes active in the absence of initiation of an effective motor activity (Rizzolatti & Craighero, 2004). This was possible to demonstrate by high-performance imaging (functional MRI) and neurophysiological (magnetoencephalography, electroencephalography) methods, which recorded the activation of brain regions (area 44 and area 6) possibly corresponding to area F5 of the monkey brain (Rizzolatti, 2005).

Thus, the hypothesis of the presence in the human brain of a neuronal observation and motor execution system similar to that initially discovered in primates was launched (Oztop et al., 2013). In the literature, the concept of brain regions with "mirror properties" appeared. Neuroimaging showed that in humans, these brain regions are the precentral gyrus that comprises the premotor ventral cortex, the posterior region of the inferior frontal gyrus and the lower parietal lobe (McGarry, 2015).

It was assumed that this neuron network facilitates a direct connection between the emitter and the receiver of a message. Thus, the actions performed by a subject become messages easy to understand by another subject who observes them, without the cognitive processing of information being necessary (Rizzolatti & Craighero, 2004), given that the mirror neuron system turns visual information into knowledge (Cinteză, 2012). At the same time, researchers have suggested the fact that in the case of humans, the neurophysiological functioning mechanism of mirror neurons might be the basis of the development of language (Rizzolatti, 2005), also having implications in the field of affectivity, through empathy (Rizzolatti & Craighero, 2004).

Starting from the premise that mirror neurons are also present in humans, fulfilling functions that go beyond those identified in primates, neuroscientists have demonstrated by the same imaging and neurophysiological methods that in reality, there is an extensive mirror neuron network in the human brain, which does not function in isolation, but has the property to receive and transmit impulses to different brain regions, including the sensory motor cortex.

According to the authors of a study published in 2015, this extensive mirror neuron network overlaps larger brain areas than those initially discovered, which are connected to the classic mirror neuron system, having a distinctive role in processing emotional information. Imaging has evidenced that this network termed by authors extra-mirroring regions is most probably located in the insula, the middle and superior temporal gyrus and the superior temporal sulcus. It has been shown that in women this network is more extensive than in men, and that stimuli creating a certain emotional context activate at different intensities the supposed "mirror" brain regions (McGarry, 2015).

The transfer of these scientific findings to medical practice was materialized by the innovation of a therapy meant to activate the extensive mirror neuron network, and thus, to modulate neuroplasticity: mirror therapy.

Mirror therapy. Hypotheses, indications, clinical results

Mirror therapy has captured the interest of researchers and clinicians due to the fact that it is an easy-to-use, economical, patient-oriented treatment method (Arya, 2016). Having the mirror neuron network as a substrate, this therapeutic approach was designed for the reactivation of brain plasticity, with the aim of restoring lost functions and preserving residual functions. The starting point was the hypothesis that the movements of a limb visualized in front of a mirror trigger neuronal connections in the motor cortex concerned (Gurbuz et al., 2016). Neurophysiological and imaging studies using functional MRI were conducted in healthy human subjects, which demonstrated that the excitability of the primary motor cortex increases when the image of one's own moving hand in the mirror is watched (Kim et al., 2016), which supports the idea of neuroplasticity modulation by applying this therapy. Mirror therapy involves overlapping the reflection of the movement of the healthy limb with the affected limb, creating in this way an optical illusion. A mirror is placed in the patient's midsagittal plane so that the image in the mirror of the healthy hemibody overlaps the projection of the affected hemibody. Under the kinesiotherapist's guidance, the patient attempts to perform symmetrical movements with both limbs, and then focuses only on observing the reflected image of the healthy limb (Guo et al., 2016). In this way, the patient has the impression of seeing the affected limb as having normal kinetics (Garbuz et al., 2016).

Neuroscientist Ramachandran and coworkers introduced the mirror therapy method to treat phantom limb pain in patients with amputations in 1996 (Guo et al., 2016). They were also the first who suggested that this technique might improve the motor function of a paretic limb after stroke (Kim et al., 2016).

Phantom limb pain

It was assumed that this particular type of pain, phantom limb pain, is triggered by the conflict created between visual feedback and the proprioceptive representation of the amputated limb. It was considered that the reduction of pain using mirror therapy might be due to the activation of mirror neurons in the cerebral hemisphere contralateral to the affected limb. Starting from these hypotheses, the authors of a study published in 2016 showed that mirror therapy performed for 15 minutes/day in patients with phantom limb pain reduced the intensity of pain, the number and duration of pain episodes in 100% of subjects (In et al., 2016). A research team in Istanbul has recently shown that in 15 patients with limb amputations, the severity of pain improved considerably after a 4 week mirror therapy program, applied daily for 40 minutes (Yıldırım & Kanan 2016).

Other studies published over the past years suggested that mirror therapy can also be extended with beneficial results to the treatment of pain in fibromyalgia, complex regional pain syndrome, diabetic neuropathy, pain of musculoskeletal origin, pain secondary to spinal cord injury (Castelnuovo et al., 2016).

Parkinson's disease

Bradykinesia, one of the cardinal signs of Parkinson's disease, is defined as a reduction in the execution speed of a movement, with the progressive diminution of the range of motion, until complete blockage during simple repetitive movements. This slowness of movements is possible due to a hypoactivation of the primary motor cortex (M1). An asymmetry of motor involvement is present in the majority of the cases, being even proposed as a diagnostic criterion.

A team of neuroscientists started from the premise that mirror therapy in association with physical training improves the performance of both hands in patients with Parkinson's disease, by increasing the excitability of both primary motor cortices. A study was carried out which was aimed at checking whether mirror therapy could be a solution for the treatment of bradykinesia in these patients, and the effects of therapy on the hand more affected by bradykinesia were monitored in particular. The study included 12 patients with Parkinson's disease (Hoehn and Yahr stages 1-3, with correctly administered antiparkinsonian medication), and 12 healthy subjects; both groups attended a mirror therapy program for 10 minutes daily, with focus on the more affected hand. Motor cortex (M1) excitability was evaluated using transcranial magnetic stimulation. At the end of the study, it was shown that the speed of movement increased after mirror therapy for both hands, in both groups. It resulted that this technique applied to patients with Parkinson's disease improves finger movement in the hand more affected by bradykinesia. Also, imaging demonstrated that mirror therapy induced an increase of M1 cortical excitability in both groups (Bonassi et al., 2016).

Stroke

Altschuler and coworkers suggested that mirror therapy provides a visual perception of the normal movement of the affected limb and through this, it might compensate for diminished or lost proprioceptive functions (Kim et al., 2016). In 1999, mirror therapy was introduced in post-stroke rehabilitation (Guo et al., 2016).

Subsequent studies provided additional evidence regarding the effectiveness of mirror therapy in the rehabilitation of motor functions in patients with limb paralysis: an increase in the gripping strength, range of motion, speed of movement, and an improvement of dexterity (Guo et al., 2016).

Garbuz et al. (2016) demonstrated the effectiveness of mirror therapy associated with conventional rehabilitation methods in the recovery of upper limb motor function in stroke patients. Patients with hemiplegia attended a daily mirror therapy program consisting of flexion and extension of the radiocarpal joint and fingers of the unaffected hand, in front of a mirror. It was shown that, applied concomitantly with conventional rehabilitation treatment methods, this therapy is beneficial for the motor recovery of the upper limbs in hemiplegic patients and might represent a new stage in neurological rehabilitation by modulating neuronal plasticity.

The authors of a study recently performed in Korea used mirror therapy along with conventional therapy for 20 minutes daily, 5 days/week, for 4 weeks in patients with upper limb motor deficit after stroke. In front of the mirror, the subjects were instructed to perform gestures imitating daily gestures – starting with the flexion and extension of the fingers and wrist in the first weeks, and ending with complex tasks such as writing and drawing. At the end of the study, an important improvement in the function of the affected upper limb was obtained, with an increase in the patients' autonomy in the performance of daily activities (Lim et al., 2016). Also, studies have demonstrated that mirror therapy can also be used for lower limbs, improving plantar dorsiflexion, an important element in the recovery of walking in patients with sequelae after stroke (Guo et al., 2016).

Using a technically advanced version of the concept of mirror therapy – virtual reality reflection therapy, a team of scientists in Korea obtained an amelioration of walking and postural balance in patients with gait disorders secondary to stroke. Therapy was applied for 30 minutes, 5 days/week for 4 weeks, with a progressive increase in the complexity of the program. Initially, the subjects watched the flexion, abduction, adduction movements of the healthy limb joints, trying to imitate them with the affected limb; in the next stage, the tasks became more complex - pushing buttons with the toes concomitantly with the above mentioned movements, first with the healthy lower limb, then with the affected one. At the end of the study, the results showed a statistically significant increase in the functional capacity of the affected lower limb, an improvement of balance and gait (In et al., 2016).

Pediatric neurological pathology

Mirror therapy has been applied in pediatric neurorehabilitation, with promising results. In children with infantile cerebral palsy, it was shown that this therapy had the potential to improve the motor function of the upper limbs. A rehabilitation program using a mirror at home was conducted in 28 children, with 7 exercise models applied 15 minutes/day, 5 days/week, for 5 weeks. An increase in the speed of execution with a reduction in the time required for completing the exercise program from the first to the last week was obtained; adherence to the program was 100% and the level of satisfaction was high (Pasquet et al., 2016).

Stroke in children is a rare pathology, which leads to long-term cognitive and motor deficits. The authors of a review aimed to present the most frequent pediatric neurological rehabilitation techniques and to examine which of these techniques can be applied and has demonstrated effects in the rehabilitation of children with stroke. Alongside methods such as occupational therapy, hand arm bimanual training (HABIT), botulinum toxin injections, robotics, electrical stimulation, studies have shown that mirror therapy may have beneficial effects in neurological rehabilitation, particularly for upper limb motor deficit, if the intervention takes place as early as possible after the disease onset (Papathanasiou et al., 2016).

Mirror therapy applied concomitantly with occupational therapy to an 8-year-old female patient with tetralogy of Fallot and operated brain abscess, with secondary left hemiparesis, resulted in an improvement of daily manual activities, with an increase in the gripping strength and the muscle strength of the affected upper limb (Hebreo & Dungca, 2016).

Empathy and autism spectrum disorders

The origin of the word *emotion* is in the word *motion*. When they are happy, people gesticulate in a way that expresses their emotions; when they are sad, they adopt a tense posture, and by structural laryngeal changes, the tone of voice changes and sobbing appears; when the emotions of another person are observed, people are "moved", experiencing feelings of pity or compassion. All these remarks are considered by neuroscientists to be more than a metaphor: it is considered that when empathizing with a person, people experience this empathy through a process of simulation of a "movement" at neural level, which also involves the participation of mirror neurons (McGarry et al., 2014).

Autism represents a pervasive neurodevelopmental disorder, which is characterized by socialization and communication dysfunctions, stereotyped behavior, and the presence of atypias in perception – for example, deficient visual processing of neutral or emotional facial expressions. Some researchers consider that the development of autism is secondary to deficient neuronal connections, particularly in the prefrontal and parietal brain regions. Persons with autism are supposed to present an impairment in recognizing emotions by means of facial expressions, although there is little literature evidence in this respect. Empathic response by gestures and affective expressions is considerably more reduced in children with autism spectrum disorders compared to children with normal mental development, a difference at neural level being observed between the two categories of children (Silva et al., 2016).

According to a recent hypothesis, autism is characterized by two abnormalities from a neuropsychiatric point of view. The first abnormality refers to social cognitive deficiencies, described as mental aloneness, the lack of contact with the exterior world, and the absence of empathy. The second abnormality is represented by sensory-motor defects such as temper tantrums, head banging and some stereotyped movements. All these deficiencies and defects are currently considered to be secondary to the abnormal development of mirror neurons (Acharya & Shukla, 2012).

There are literature data suggesting that the inability of children with autism to normally interact with other people and manage ordinary life situations results from the absence of a normofunctional mirror neuron system (Palau-Baduell et al., 2011). Recently, this hypothesis of mirror neuron dysfunction in persons with autism has become the focus of attention of neuroscientists. Silva et al. (2016) conducted a study to assess the functional capacity of mirror neurons in children with autism. The aim of this study was to investigate the reactivity of the mirror neuron system to emotional stimuli in subjects with autism and in subjects with the same demographic characteristics without autism or mental disease, and to test the hypothesis that these subjects can be stimulated by biofeedback.

The study included 30 children, of which 10 with demonstrated autism, 10 with intellectual deficit and 10 neuropsychically healthy children. Electroencephalography was performed at two times, before and after cerebral stimulation, and changes occurring in the brain regions theoretically considered to be correlated with the presence of mirror neurons were monitored. The results showed that for all 3 groups, the brain stimulation process induced an additional activation of the studied brain areas. It was proved that mirror neurons in subjects with autism are present in the studied cortical areas and are reactive to situations involving emotion processing. In other words, children with autism smile or are sad inside themselves (they have an emotional experience), but they do not show these emotions (they do not have emotional expressions). This behavior is probably due to the fact that children with autism do not have the cognitive ability to process environmental data and internal data adequately to generate a visible motor expression.

The authors of the study concluded that since the same brain activation was recorded in subjects with autism and healthy subjects, the difficulty of patients with autism in expressing their emotions is not secondary to the absence of mirror neurons. Also, the authors considered that mirror neurons are present in subjects with autism and tend to react when the subjects are exposed to emotional stimuli. Thus, the absence of an adequate emotional expression and the lack of harmony observed during interactions between subjects with autism and healthy subjects are more probably unrelated to the activation of these neurons or these are not located in the studied cortical area (Silva et al., 2016).

Another study (Dapretto et al., 2006) proved the contrary: neuroimaging showed that pediatric subjects with autism did not exhibit mirror neuron activity in the inferior frontal gyrus (pars opercularis) compared to healthy children in the control group, in an exercise of imitation of facial expressions.

These differences can be explained by studies involving functional MRI which suggest that a more extensive network of human brain areas has "mirror" properties than was initially thought (Acharya et al., 2012), but also by the finding that mirror neurons are integrated in an extensive neuronal network (amygdala-hippocampal circuit, caudate nuclei, the cerebellum, and frontal-temporal regions) whose functioning is deficient in autism (Lauvin et al., 2012).

If mirror neurons are really involved in the interpretation of complex situations, the interruption of the neuronal circuit in which they are involved might explain the classic symptoms of autism and the lack of social skills in these patients (Silva et al., 2016), and might open perspectives using neurofeedback training for individuals with autism (Saffin & Tohid, 2016).

Further research providing new data about the influence on the functionality of mirror neurons might be the key to the treatment of adaptation disorders such as autism.

Conclusions

1. Mirror therapy was designed by neuroscientists secondarily to the discovery in the human brain of a neuronal observation and motor execution system – the mirror neuron network.

2. Mirror therapy was introduced in medical practice for its potential, demonstrated by imaging and neurophysiological methods, to reactivate brain plasticity, with the aim of restoring lost functions and preserving residual functions.

3. Initially used for the treatment of phantom limb pain, mirror therapy is currently successfully applied as an effective, accessible, patient-oriented and adverse effect-free neurorehabilitation method, associated with classical rehabilitation methods.

4. The main indications of mirror therapy are: improvement of phantom limb pain, reduction of bradykinesia in Parkinson's disease, rehabilitation of stroke survivors. It is also indicated in pediatric neurorehabilitation, with clinical effects demonstrated by studies.

5. The neurophysiological substrate of the activation of mirror neurons in the presence of visual and auditory stimuli, as well as their impressive potential to be the solution in neurological rehabilitation remains an area open to research.

Conflicts of interest
Nothing to declare

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