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DEVELOPMENT OF A DEVICE FOR MIRROR THERAPY

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ABSTRACT. Previous research on the interconnections between brain activity and actions had led to the discovery of mirror neurons, neurons that have two particularly important roles: they mediate the imitation of movements based on visual information, and they underlie the understanding of actions. Mirror therapy is a relatively new, non-invasive therapy based on the use of visual feedback in recovery. Since 1996, it has been introduced in medical rehabilitation programmes, targeting conditions such as: hemiplegia after stroke, gait recovery after stroke, improvement of finger coordination in Parkinson's patients, reduction of phantom limb pain after amputations, and chronic pain from hand osteoarthritis, fibromyalgia, and complex regional pain syndrome. The device that is the subject of the present work presents a new constructive variant of the mirror box, which offers a much more efficient method of applying mirror therapy in various conditions, both at the level of the upper and lower limbs. The results of two assessments on the effectiveness of visual stimulation in recovery, carried out with the help of this device, first on the recovery of the hand functionality in subjects with hemiparesis after ischemic stroke and second assessment in the treatment of chronic pain of subjects with hand osteoarthritis will also be presented.

Keywords: *mirror therapy, visual feedback, neuroplasticity, kinesthetic memory, stroke, phantom limb pain*

REZUMAT. ***Dezvoltarea unui dispozitiv pentru terapia oglindă.*** Cercetările anterioare privind interconexiunile dintre activitatea cerebrală și acțiuni au dus la descoperirea neuronilor oglindă, neuroni care au două roluri deosebit de importante: mediază imitarea mișcărilor pe baza informațiilor vizuale și stau la baza înțelegerii acțiunilor. Terapia prin oglindire este o terapie relative nouă,

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neinvazivă, bazată pe utilizarea feedback-ului vizual în recuperare. Din 1996, a fost introdusă în programele de reabilitare medicală, vizând afecțiuni precum: hemiplegia după un accident vascular cerebral, recuperarea mersului după un accident vascular cerebral, îmbunătățirea coordonării degetelor la pacienții cu Parkinson, reducerea durerii membrelor fantomă după amputații și durerea cronică cauzată de osteoartrita mâinilor, fibromialgia și sindromul durerii regionale complexe. Dispozitivul care face obiectul lucrării de față prezintă o nouă variantă constructivă a cutiei cu oglinzi, care oferă o metodă mult mai eficientă de aplicare a terapiei prin oglindire în diverse afecțiuni, atât la nivelul membrelor superioare, cât și al celor inferioare. De asemenea, vor fi prezentate rezultatele a două evaluări privind deficiența stimulării vizuale în recuperare, realizate cu ajutorul acestui dispozitiv, prima privind recuperarea funcționalității mâinii la subiecții cu hemipareză după un accident vascular cerebral ischemic și a doua evaluare în tratamentul durerii cronice a subiecților cu osteoartrită a mâinii.

Cuvinte-cheie: *terapie prin oglindire, feedback vizual, neuroplasticitate, memorie kinestezică, accident vascular cerebral, durerea membrului fantomă*

INTRODUCTION

Stroke is a major problem affecting the health of the population worldwide. Although compared to cardiovascular diseases, the prevalence of stroke is much lower, the severity is given by the fact that patients who survive a stroke often present persistent symptoms such as: impairment of motor functions, pain, ataxia, sensory deficits, perception deficits, aphasia, depression, dementia or other deficiencies of cognitive functions, also representing the main etiological factor of the installation of disabilities (Neagoe,2013). Another condition that causes obstacles to rehabilitation is pain. Pain is not only a state of physical suffering, it also has a strong emotional component, causing a state of psychological suffering. A type of neuropathic pain is also "phantom limb pain", following amputations (Richardson & Kulkarni, 2017).

Mirror neurons - were discovered in the early 80s by a group of Italian researchers from the University of Parma, who identified a special type of nerve cells with a special role in direct, automatic and unconscious cognition. of the environment, in learning simple and complex motor acts, based on imitation, using visual information (Gazzola & Keysers, 2009). Thus, the mirror neuron system is involved both in the immediate repetition of actions performed by other people, and in learning behaviors through imitation, thus they are also responsible for understanding intentions. So, their defining characteristic is the close relationship between the motor information they encode and the visual information they respond to, connecting brain areas responsible for sensory and motor processing (Rizzolatti et al., 2004, Rizzolatti, 2005, Schieber et al., 2009). An example would be "contagious yawning", the studies of Robert Provine (2005), concluded that this manifestation is a social behavior, ordered to brain level, where mirror neurons are also involved, or another example of this would be laughter (Haker et al., 2013, Provine, 1996). Other studies have linked these neurons to empathy in relating, understanding, with other people (Hausser, 2012). Neuroplasticity is the property of the brain to change through learning, it having a determining role in the process of functional recovery. Thus, stimulated neurons can create numerous synapses to increase the effectiveness of neural circuits or to transfer certain lost functions. However, this reparative process is not sufficient and cannot ensure the replacement of all lost neurons, respectively it cannot fully compensate for the recovery of lost neural functions (Bulboacă, 2003, Becker, 1953). In the process of learning or relearning deficient motor functions, repetitive movements are particularly important, which lead to the coordination of movements, their automaticity and the creation of motor engrams (Carpinella & Ferrarin, 2011). In the case of mirror therapy, these mirror neurons are activated by observing the mirror image, which replaces the image of the affected or amputated limb.

Neuroscientist Vilayanur Subramanian Ramachandran, a professor at the University of Cambridge, is considered to be the inventor of the mirror box and was also the first to introduce the visual feedback effect of the mirror in 1996 as a treatment method for reducing phantom limb pain in people who have suffered amputations (Guo et al., 2016). The aim of the therapy was to give the brain the illusion that the amputated limb exists, by placing a mirror in the sagittal plane, between the patient's limbs, using the hypothesis that the reduction of pain through mirror therapy would be due to the activation of mirror neurons in the brain hemisphere located on the contralateral side of the affected limb. Later, together with his colleague, professor Eric Lewin Altschuler, they implemented the method for hemiplegic patients as well. In this case, the goal was to improve motor control, deficient due to a stroke (Kim et al., 2016). The results of the studies, carried out in patients suffering from phantom limb pain, showed that mirror therapy reduced the intensity of pain, the number and duration of painful episodes (Lee et al., 2009, Sae et al., 2012, Sayegh et al., 2013, Yildirim et al., 2016). Mirror therapy favors the learning/relearning process due to the essential role that visual information plays in therapy, the credibility factor of the viewed image being also influenced by the quality and correctness of the image received by the visual receptor. In this regard, working protocols, Rothgangel and Braun (2013) propose that any item such as jewelry, watches, etc., be removed from the healthy limb, even certain scars or tattoos be covered with a skin-colored patch, as pictured visualized to be as real as possible, so that the patient perceives that the affected limb is healthy. Mirror therapy has been present in numerous studies, its field of application knowing a continuous development. Some studies have demonstrated the effectiveness of mirror therapy in various pathologies, starting from motor deficits in the upper limbs in the case of hemiplegic patients after a stroke (Nistor et al., 2017), improving dexterity, movement speed, or the improvement of plantar dorsiflexion for gait recovery in patients with post-stroke sequelae (Guo et al., 2016, Hu et al., 2006), and studies in Parkinson's disease patients, which showed an improvement in finger movement in the affected hand and an increase in cortical excitability (Bonassi et al, 2016). Other research has aimed to study the effectiveness of mirror therapy in reducing other types of pain, such as pain in fibromyalgia, complex regional pain syndrome, diabetic neuropathy, pain of musculoskeletal origin (Castelnuovo et al., 2016).

To date, numerous device variants have been created for the application of this therapy. A first category of devices would be those in which the diseased limb, or amputation stump, is inserted to be masked in a box, and on the outer wall of the box is a mirror that reflects the image of the healthy limb. which the brain perceives, seeing it in the mirror, as the image of the affected limb. This type of device has the disadvantage that the person using it has to sit in an asymmetrical position with the neck flexed and rotated to look into the mirror on the outer wall of the box. This position is tiring, creates discomfort and cannot be maintained for a long time. In addition, in the patient with spastic paresis due to cerebral or spinal pathology (vascular accident, trauma, tumor) this position produces aggravation of spasticity and a greater limitation of mobility due to the tonic postural reflex of the neck (O"Dweyr, 1996, Pandyan, 2005). Thus, the positional discomfort of the user leads to a decrease in the time of use and together with the worsening of the spasticity decreases the efficiency of the use of the device. A second category are devices that have made an image acquisition of the healthy limb with the help of a photo or video camera, placed above it. The image of the healthy limb was then converted by specialized software into a mirror image on a monitor in front of the patient, under which the affected limb was placed in a box. This category of devices presents the disadvantage that the location of the camera being in the patient's visual field and the fact that the patient sees one of his limbs, leads to the loss of credibility of the image on the screen, reflecting the illusion that the affected limb is healthy.

OBJECTIVES

1. description of the innovative device
2. description of the effectiveness of mirror therapy with the innovative device in the case of people with hemiparesis and those with arthrosis of the hand

METHOD

The designed device (figure) has the following components: a box with two rooms (A) and (B), a video camera (1), a mirror (4) and a monitor/screen (6), under the monitor being placed a led strip, for lighting the space as needed so that the physiotherapist can see how the patient performs the movements and help him if needed. The room (A) is equipped with two rails on which two interchangeable walls (c) and (d) slide, inside the room (A), on wall c there is also a hole (g) for inserting the patient's sick limb. A mirror (4) is placed on the common wall with the room (B), and on the wall opposite the mirror (4) a 3D camera/webcam (1) is positioned, also tilted, and at the base of the room (A) is a plan inclined (a), on which the patient's healthy limb is positioned, the mirror (4), the inclined plane (a) and the 3D video camera (1) form an assembly that allows a personalized adjustment of the position and inclination of the healthy limb. Thus, the image taken from the 3D camera/webcam (1) from the mirror being clear and realistic, The image is transmitted in real time to the monitor/screen, placed outside the box, on the upper part of the room (B) and can also be viewed with the help of 3D glasses. (Ver & Ungur, 2021) (figure 1)

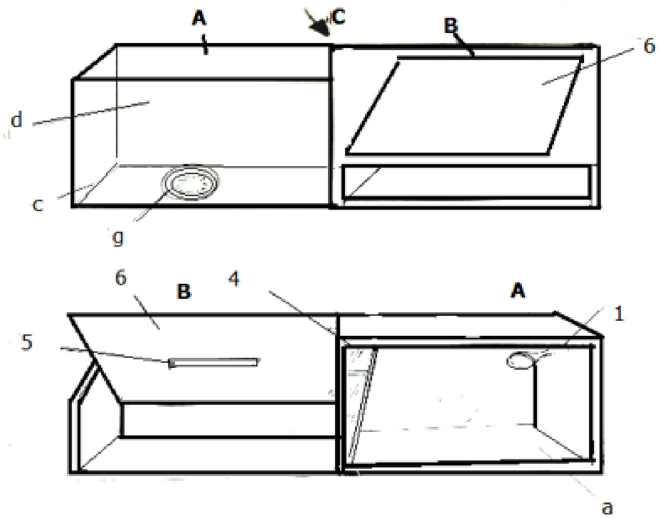

Figure 1. Device components

Also, the constructive solution of the device allows the therapist to observe and, if necessary, help the patient in making movements with the affected hand. (figure 2)

Figure 2. Therapist-patient relationship mode

By using 3D glasses, the patient can focus only on the image, not being distracted by what is happening around him (external visual stimuli) and thus being able to concentrate better on the therapy. Also, the vicious position of the patient has been eliminated, he no longer has to lean and look sideways at the mirror – as in classic models but looks at the screen/tablet or can use a VR system to view the rendered image.

Figure 3. Viewing mode of the image

In order to capture the image in the mirror as faithfully as possible, so that the visualized image is almost impossible to differentiate from the natural image, the inclined positioning of the mirror was realized, as well as an inclined plane for the positioning of the healthy limb. At the same time, the device can be used both for the treatment of the upper limb and the lower limb, with the possibility of positioning the device on the right or left side of the patient.

Two cases were studied in which mirror therapy was applied with the help of the designed device, one regarding the recovery of the paretic hand after stroke and the other regarding the reduction of pain in osteoarthritis of the hand.

In the first assessment - a group of 7 people, 5 women and 2 men aged between 50 and 75 years, who share the diagnosis of sechelal hemiparesis after ischemic stroke, was studied.

The hemiparetic subjects met the following characteristics: cooperative behavior, diagnosis of sechelal hemiparesis after ischemic stroke, cognitive skills: be able to focus for at least ten minutes on the reflection in the mirror and follow the instructions given by the therapist, sufficient trunk control to be able to sit unsupervised in a wheelchair or regular chair throughout treatment, stable cardiorespiratory functions. The hemiparetic subjects were informed about how to apply the therapy, and the exercises were explained to them, as well as the fact that they will always be practiced below the pain threshold. The training of the skill to practice individually was also pursued. Once hemiparetic subjects understood the exercises and were able to perform mirror therapy without the guidance of a therapist, self-directed treatment was initiated. In the first sessions it started with simple exercises, such as: flexion and extension movements of the fingers and wrist, then, gradually the range and complexity of the movements increased, realizing various types of prehensions. Testing of subjects was done at the beginning and end of the exercises period, according to the test procedure, the way of assessment and scoring of G-scores for simple hand movements and H-scores for complex hand movements of the Motor Assessment Scale for Stroke CARR. **The second assessment** was carried out on a group of 10 female with hand osteoarthritis, aged between 45 and 75 years, to whom mirror therapy was applied to reduce hands chronic pain. Both before and at the end of the exercises period, the subjects with hand osteoarthritis were tested, with the following scores: VAS for pain assessment, Stanford HAQ for autonomy assessment and Jebsen-Taylor for hand function assessment. The subjects with hand osteoarthritis met the following characteristics: cooperative behavior, with cognitive and control skills, common diagnosis of arthrosis of the hand. The exercises protocol was identical to that of the first batch, aimed at familiarizing the subjects with hand osteoarthritis with this therapy, training the ability to work independently, and progressively increasing the difficulty of the exercises.

In both assessments, the tests were done on both hands, at the beginning and at the end of the test period.

RESULTS

The assessment of hemiparetic subjects is indicated in figure 4 and the evolution performed by an hemiparetic subjects, at the beginning and at the end of the exercises program in figure 5.

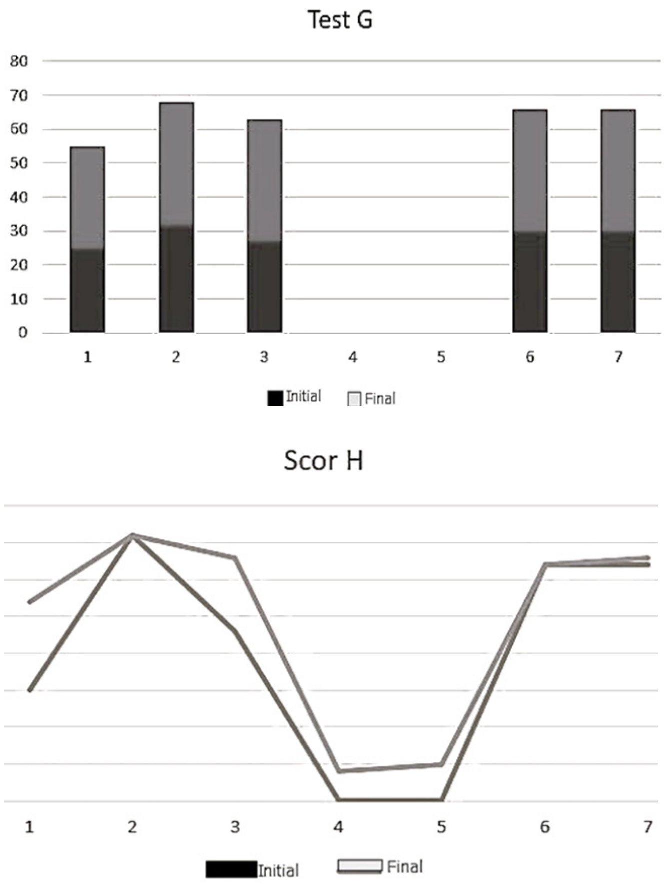

Figure 4. Graphs of initial and final G and H motor assessment scores

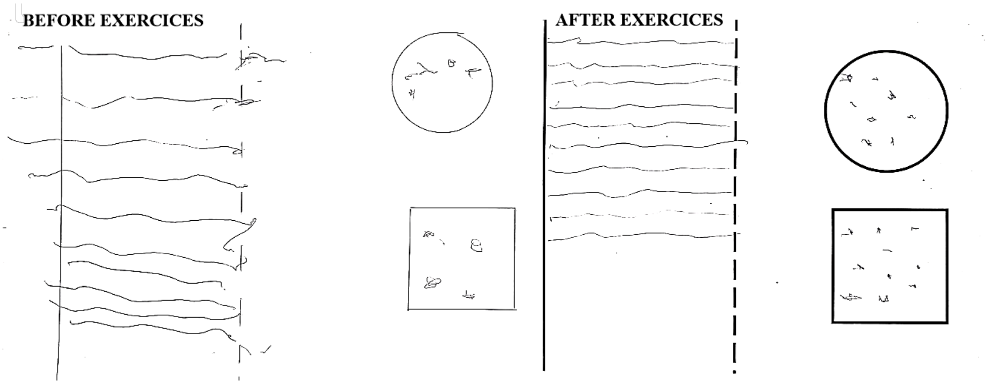

Figure 5. Graphical test example

From the observations collected from hemiparetic subjects regarding the effectiveness of the therapy, the following aspects were noted: - the tremor has reduced, movement coordination has been improved, the prehension has improved, opposability was achieved faster and more precisely, they noticed a reduction in pain and they felt a slight elasticity of the hand, they found a better concentration in doing the exercises and an increase in motivation, none of the patients noted negative effects.

The assessment of subjects with hand osteoarthritis, present the followings results (figure 6):

- t**he VAS test (visual analogue scale – pain test)** revealed a reduction of joint pain (figure 6a);

- the HAQ index (disability index), indicated a significant improvement in autonomy (figure 6b);

- **the Jebsen-Taylor score (hand functionality score)** showed an improvement in hand functionality (figure 6c).

Regarding the feedback of the subjects with hand osteoarthritis regarding the efficiency of the therapy, the following were reported:

- a significant reduction in pain
- feeling of relaxation and elasticity of the hand and fingers- improving coordination and safety
- increasing confidence and motivation for recovery
- no subjects with hand osteoarthritis noticed the induction of pain as a result of the therapy or any other unpleasant sensation

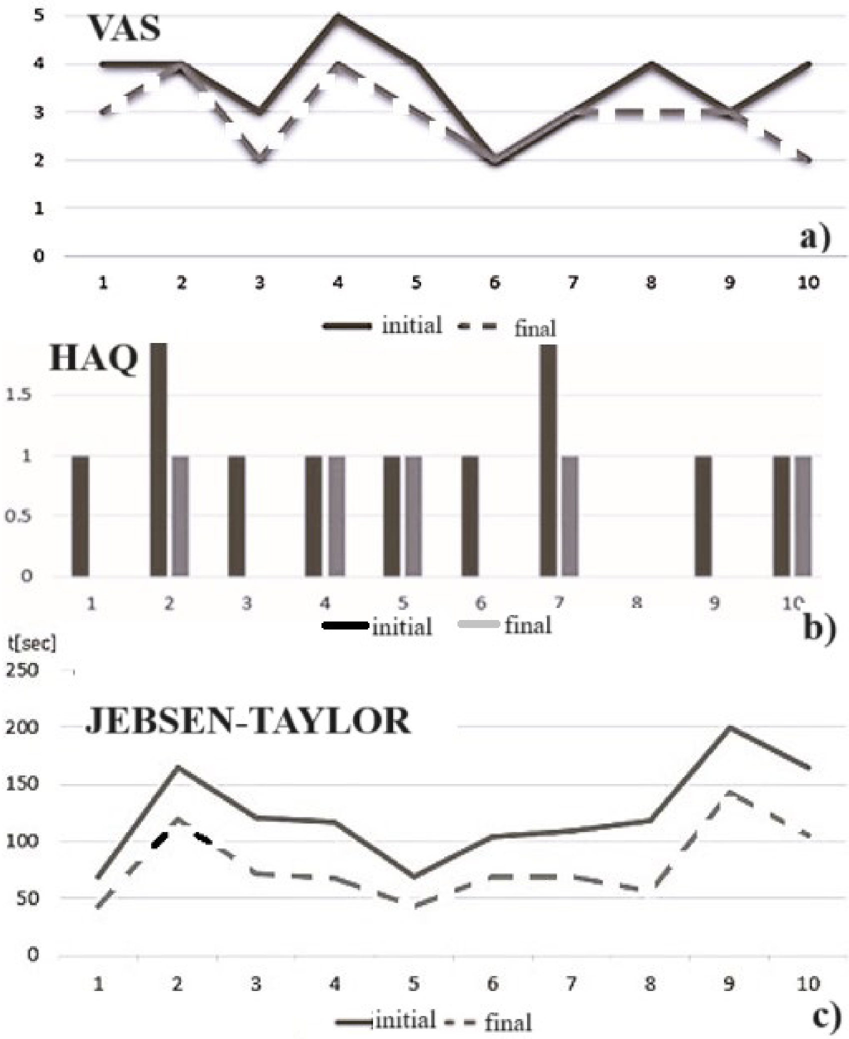

Figure 6. a) – VAS score; b) – HAQ score; c) Jebsen-Taylor index

DISCUSSIONS

When they found out what the exercises consisted of, most subjects were reluctant. However, from the very first session, they were surprised by the credibility of the visualized image, which gave them the "false" feeling that they could indeed mobilize their affected limb and they looked under the screen to see their affected limb, even though they had been repeatedly warned not to do so. However, they said that the image was so real that they wanted to check whether the affected limb was indeed performing the movements they had visualized. At the end of the exercise period, patients noticed improvements in both functionality and pain reduction. Our device provided good results in terms of functional hand recovery for hemiparetic subjects and in terms of pain relief for subjects with osteoarthritis.

The features proposed by the designed device are:

- to create a credible image visualized in real time, the basis of treatment being visual feedback
- ensure patient comfort and reduce the effects of spasticity due to incorrect posture
- to offer the possibility to perform the treatment also at home - where there is peace and quiet in the home environment, without being disturbed by external disturbing factors
- by the constructive solution to offer the possibility of its acquisition by the widest possible category of patients: in the case of post-stroke recovery and other neurological conditions, for the treatment of pain from various conditions, including phantom limb pain after amputations, prevention of complex regional hand pain (post-stroke, post-surgical, post-traumatic), etc. Thus, reducing pain may implicitly lead to a decrease in medication consumption.

Our observations suggest that the new device deserves to be tested in clinical trials for its efficacy in the recovery of functional deficits caused by stroke and in the treatment of chronic pain.

CONCLUSIONS

Mirror therapy is a therapy based on the effect of visual feedback in neuromotor recovery by activating neuroplasticity phenomenon. Also, thanks to the visual feedback, which is in real time, the patient's motivation is stimulated and his active involvement contributes to increase the efficiency of the recovery process, thus reducing the recovery time. Repetitive exercises also play an important role in the application of therapy, with the help of which the kinaesthetic memory of movements is maintained.

Many studies in recent years have confirmed the effectiveness of using mirror therapy in rehabilitation exercises, for example the paper by Hyunjoong, Eunsang, Jihye, and Seungwon (2023) on the use of mirror visual feedback in the recovery of upper limb function in post-stroke patients, Mohammed Ismael

Elsepaee's (2016) paper on the use of visual feedback in the recovery of hand functions in children with hemiparesis, or Mei-Hong, Ming, Ming, Mei-Fang, Xu-Dong, Fang, Ye-Ping, and Ya-Ping's (2020) paper based on the mirror neuron theory of post-stroke upper limb recovery.

Through the evaluations presented in this paper, we have confirmed the effectiveness of using mirror therapy in rehabilitation exercises using the designed device. It has enabled the effectiveness of this therapy by: Avoiding the subject's vicious position (of looking at the mirror from the side) and keeping him in a correct and comfortable position, and by using 3D glasses he can better focus on the exercises without being affected by external visual disturbing factors, it can be used both in hospital and at home, where, being in a home environment, can concentrate better on the exercises and perform them for longer, which helps to reduce pain and thus recovery time, can be used for a variety of pathologies and stages of damage, and can be made in a variety of versions so that it can be purchased by a wide range of patients.

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