

Justyna TWARDZIK¹, Karolina MOLIK¹, Mariola DYLONG¹,
Magdalena HOEFTMANN², Aleksandra SZEMA¹, Julia SALINGER¹,
Piotr WODARSKI¹, Joanna BARTNICKA², Iga GARBOWSKA³, Jacek JURKOJC¹

Chapter 2. APPLICATION SUPPORTING COGNITIVE FUNCTIONS DIAGNOSTICS AND REHABILITATION OF PATIENTS AFFECTED BY AFTER-STROKE HEMISPATIAL NEGLECT SYNDROME

2.1. Introduction

The *hemineglect syndrome*, also known as *unilateral neglect* or *hemispatial neglect*, is a complication following an ischemic stroke or a disorder observed in the course of a brain tumor. Damage to the brain's structures contributes to the development of the disorder, but the exact cause of the disease is yet not fully understood.

The essence of this disorder is incorrect processing of information about the personal and extracorporeal space concerning the side opposite to the damaged hemisphere. Hemispatial neglect occurs most often, but not always, after damage to the right part of the brain, which means that a patient after a stroke of the right hemisphere ignores the existence of the left side of the body or the environment, and does not respond to stimuli acting on this side [1, 3, 7, 17]. Patients are not necessarily aware of their limitations in functioning and it significantly deteriorates their quality of life, making it very difficult to perform daily activities. Some of the symptoms of hemineglect syndrome (HS) are: one-sided unawareness or altered sensation of one's body - the patients may find their limbs unnecessary or ignore one side of the body during daily activities. This disorder manifests itself for example when the patient puts on only one sleeve, one shoe or shaves only half of the face. Other symptoms are: neglecting one side of the surrounding space

¹ Department of Biomedical Engineering, Silesian University of Technology.

² Department of Organization and Management, Silesian University of Technology.

³ Department of Physiotherapy, Jerzy Kukuczka Academy of Physical Education in Katowice.

(e.g. seeing people in the field of view only on the right side), ignoring stimuli on the neglected side or unilateral akinesia, i.e. patient's failure to use the limbs on the left side despite the lack of paresis [8, 17].

2.1.1. The hemineglect syndrome diagnostics

Isolated motor symptoms rarely constitute the basis for a diagnosis of unilateral neglect. The dynamics of symptoms has the greatest impact on the correct diagnosis of the disorder. Contact with the patient and analysis of their behavior are also important. A number of neuropsychological studies allow to obtain a complete picture of the disorder and link motor and perceptual abnormalities with the patient's imagination. That allows therapists to understand the way patients perceive their own body and environment [7, 17].

In the clinical picture of the disease, attention is paid to disturbances in the reproduction of visual or auditory sensations, as well as to the orientation towards external stimuli coming from the neglected side. The most frequently used diagnostic tool is the BIT, i.e. the Behavioral Inattention Test [16], or more precisely a shortened version of the BITC (Conventional Subtests of the Behavioral Inattention Test). This test consists of paper-and-pencil tasks of varying difficulty. The method includes tests of drawing, dividing lines, copying drawings or drawing from memory [15]. As a part of the copying test, the patient is asked to redraw a simple picture consisting of individual, smaller elements. A symptom that allows for presuming hemispacial neglect in a patient is redrawing only a part of the picture (Fig. 2.1). The search (cross-out) test (Fig. 2.2), in turn, consists of searching for stars of a given size by the person. Figure 2.2 shows an example of how this type of test was performed by a person with unilateral neglect syndrome. The principle of performing each of the above-mentioned tests is very similar. The patient visually searches for given symbols or objects on the board or marks their centers (as in the case of the line dividing test). Selected methods of diagnosing the hemispacial neglect syndrome are presented below [17].

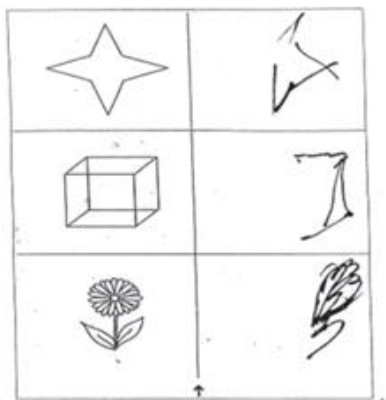


Fig. 2.1. Copy test [17]
Rys. 2.1. Test kopiowania

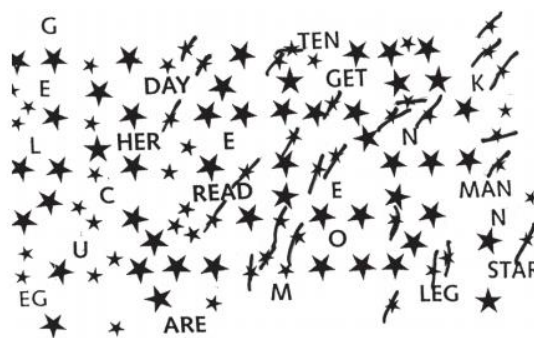


Fig. 2.2. Star search test [17]
Rys. 2.2. Test wyszukiwania gwiazdek

2.1.2. Conventional rehabilitation of the hemineglect syndrome

The rehabilitation of people after strokes should be multidisciplinary. It is important that the rehabilitation team consists of people with different specializations, including a doctor, physiotherapist, orthopedist, neuropsychologist, speech therapist and a nurse. Rehabilitation of patients diagnosed with unilateral neglect should be started as soon as possible. The aim of rehabilitation is to restore total or partial efficiency, as well as to prevent the effects of long-term immobilization and reduce the risk of abnormal (pathological) motor patterns [2, 4, 10, 14]. The therapy of people with spatial hemineglect should make the patient aware of the existing attention deficit, as greater awareness of the disease increases the patient's motivation [11]. In the treatment of people with hemineglect syndrome, in addition to the principles used in traditional post-stroke rehabilitation, emphasis is placed on the use of visual and acoustic stimuli, stimulating and encouraging the use of limbs on the neglected side - symmetrical activation of the limbs, as well as exteroceptive stimulation, i.e. providing tactile stimuli, massages and muscle stimulation with low-frequency currents (FES). An important aspect in rehabilitation is also the use of Kabat proprioceptive priming and Bobath stimulation, the use of sensory modulation techniques, vestibular stimulation, reference to remembered motor experiences and the use of psychological compensation techniques, including: lateral signaling, rehabilitation of attention disorders and visual coordination - computer-assisted movement or visual-spatial searching training [11-13]. In addition, general methods used in post-stroke rehabilitation, such as the method of forced movement (CIMT) and the same methods as in diagnostics, are used in the

rehabilitation of people with hemineglect syndrome, e.g. copying patterns, reading texts, arranging puzzles or finding differences in pictures [17].

2.1.3. Rehabilitation of the hemineglect syndrome using VR technology

Due to computer technology development and the possibilities offered by VR technology, the use of virtual reality in rehabilitation of people with hemispatial neglect syndrome has become the subject of many studies. Numerous applications use multisensory stimulation, which is extremely beneficial in the rehabilitation of the disorder. Additionally, all solutions use an uncomplicated, low-detail VR environment that does not distract the patient. Most often, in VR rehabilitation games, we can find pointing to or searching for specific elements on a virtual stage, as well as additionally moving them to specific places. One of the most popular solutions used in the rehabilitation of side skipping is the use of the urban environment, where the patient's task is to cross the road to the other side of the road [5, 6, 9]. The difficulty of the task is the movement of cars and, in some cases, pedestrians. Depending on the application, the difficulty level is adjustable, and the games use various tips in the form of car headlights or a horn. However, there are few applications with highly realistic graphics that increase patient involvement in therapy and translate into improved outcomes. In addition, not all scenarios are similar to everyday activities - some of them are quite abstract, which can make it difficult for the patient to understand the rules of the game and reduce his involvement.

The use of virtual reality in the treatment of HS can be beneficial in many respects. Unlike conventional diagnostic methods, VR methods allow therapists to monitor the patient's behavior in dynamic activities involving many senses at the same time. An example would be a simulation of driving a car or walking in a park. The advantage of VR methods is also the possibility of recording the movement of the eyeballs, limbs and head, as well as recording and analyzing the patient's reaction to stimuli. This can significantly facilitate rehabilitation, as it is then possible to adapt the VR application to the patient and to the degree of his disability.

Rehabilitation of motor functions

Rehabilitation of motor functions with the use of virtual reality takes place by introducing an avatar figure into an artificially generated image, which the patient can control through gestures and movement of the whole body. Performing activities in the virtual world translates into the improvement of optimal movement patterns in everyday life, as well as the performance of movements similar to natural ones during exercise. The scenarios which are present during the rehabilitation session would not be possible in the real world. The advantage of rehabilitation with the use of VR is the variety of activities, as well as repeatability, which does not significantly affect the patient's fatigue. Depending on the severity of the disease, the therapist individually selects the intensity and type of training, and can also adjust other game parameters, such as location of the stimulating element depending on the position of the head. The patient's results along with the relevant examination parameters are recorded in a numerical manner, which allows the progress of rehabilitation to be monitored. A patient who has a problem with moving a limb, seeing it artificially generated in virtual reality, is activating the mirror neurons, which stimulate the mechanisms of neuroplasticity. Thanks to this process, it is possible to rebuild the damaged structures of the pyramidal system in the brain

Rehabilitation of cognitive functions

Virtual reality allows stimulating everyday life situations and it helps to exercise cognitive functions. The patient obtains real-time feedback, with no physical consequences of the made mistakes. The advantage of this training is simplicity and intuitiveness, which is necessary due to the limited acquisition of new skills by patients.

2.1.4. Examples of existing VR solutions dedicated to the unilateral neglect rehabilitation

There are currently many devices on the market that support the rehabilitation of patients using virtual reality technology. Among them are those that help to recover stroke patients, as well as people with hemiplegia. An example of such a system can be NIRVANA [19]. It is a virtual reality based medical device, specially designed to support physical and cognitive rehabilitation in patients with neuromotor and neurological disorders such as stroke, cerebral palsy, Parkinson's disease or autism. This

system creates projections of the environment on a flat surface, wall or floor, allowing the patient to completely immerse himself in the virtual world. Importantly, this device does not require the use of additional elements on the patient's body, such as HMD goggles or markers. Another example is MYRO [18], in which, as in NIRVANA, there is no need for any auxiliary devices. Myra, the therapeutic panel was created with the aim of computer-assisted, motor and cognitive therapy of the upper limb. The device is used in typical occupational therapy and physiotherapy. The movements of the upper limb, repeated in the available exercises, provide internal and external stimulation and strengthen the neuroplasticity that modifies the central nervous system to restore lost functions. Another example of a system used during rehabilitation is Rewellio [20], a device based on a combination of virtual reality technologies (using HMD goggles) and a hand tracking system to stimulate the rehabilitated areas of the brain. Rewellio supports the therapy with a variety of engaging VR games. However, despite the wide selection of technological solutions designed for rehabilitation, it can be easily seen that most of them are dedicated to physiotherapy centers. However, there are no solutions that would be available to a wide audience, enable systematic rehabilitation at home and promote exercises under the supervision of a qualified physiotherapist. This gap in the market could be filled by an application that is affordable and technologically intuitive to use and has clear instructions, tailored to the needs of older patients.

The analysis of market and scientific works covering similar themes, it has been found that there is a need for further research into the use of VR in the rehabilitation of hemispatial neglect. The aim of the study is to develop indications for the diagnosis and rehabilitation of cognitive functions of people affected by hemispatial neglect using virtual reality technology and to prepare a VR application that would allow verification and correction of the adopted indications.

2.2. Methodology

The correct implementation of the therapeutic application requires a proper indication of the patient's needs. As the hemispatial neglect syndrome most often accompanies injuries occurring in the right hemisphere of the brain, dysfunction is observed in the area of its action in patients with HS. Table 2.1 shows the specific tasks performed by both hemispheres of the brain.

It is common that damage to the right hemisphere is accompanied by paresis of the left side of the body, which makes recovery difficult. In addition, people with unilateral skipping syndrome require rehabilitation tailored to their needs, which takes into account the inability to perform the task with functions controlled by the healthy hemisphere. As a result of damage to the center responsible for abstract thinking and creativity, patients are focused on performing tasks and precise thinking, which means that messages and instructions must be formulated in a simple and intuitive way, and should take into account the specificity of the reception of information by the undamaged hemisphere and brain centers. In the rehabilitation of HS, it is extremely important to maximize the stimulation of the side neglected, i.e. the use of more stimuli acting on the side opposite to the damage.

Table 2.1

Tasks performed by different hemispheres of the brain	
Left hemisphere	Right hemisphere
proves the right side of the body	shows the left side of the body
remembers information given verbally, digitally	remembers information provided vividly
analysis	synthesis
works sequentially	operates globally
solves tasks	produces dreams
remembers facts, grammar, spelling	differentiates between colors
	understands metaphors

This stimulation can occur through the use of a blinking light source, moving elements or objects changing color. Importantly, the delivered stimuli must be strong and unexpected in order to attract the patient's attention. An example of such a stimulus may be putting the rehabilitated person in a virtual threat situation coming from the neglected side of the body. However, it should be noted that the excess of sounds used in the program will distract the patient. Applications used as part of rehabilitation should be adapted, as far as possible, to the rehabilitated person in terms of gender, age or interests. The formulated tasks should also be similar to the daily activities or related to the

patient's profession, which arouses the patient's motivation and interest in the therapy. In addition, an important aspect when designing such systems is influencing the feelings and emotions of people with HS, for example by using the images of relatives or using a reward system other than points.

2.2.1. Indications for the VR application

In response to the presented needs of people struggling with hemineglect syndrome, indications were formulated, on the basis of which the designed application was created. According to them, the designed rehabilitation system should use immersive reality, allowing for a high level of player's immersion in the virtual world, and thus deepening his involvement in rehabilitation. Motivating goals and challenges, emotional impact, tasks similar to daily activities, and a realistic scene are also factors that increase the patient's enthusiasm for exercise. The use of familiar environments, behaviors and tasks reduces stress for the patients as well as prevents their discouragement in the initial stages of exercise. Due to special requirements of people with damaged one hemisphere of the brain, usually the right one, tasks and messages must be clearly formulated, preferably step by step. Moreover, it is worth to use multisensory cues, sound and visual effects in the application, which allow patients to perform tasks or draw their attention to a given element of the game, especially on the neglected side. What is important, the rehabilitation of neglected side should be performed as frequently as possible to bring the desired effect. An important aspect is also a feedback, that is informing the patient about correctly or badly performed tasks and progress in recovery. When creating a VR application for the rehabilitation of HS, it should be remembered that this rehabilitation should also include the features of conventional post-stroke therapy. So, an important aspect is the involvement of the body limbs, which can improve motor skills and increase patient's awareness of the body parts affected by the disorder, which also contributes to the effectiveness of rehabilitation. The last two important factors when designing an application that potentially would be widely accessible to individuals struggling with varying degrees of cerebral impairment and facing multiple disabilities, are personalization, as well as accessibility and ease of use. Personalization of the application will allow the therapist or the patient who exercises at home to adjust the parameters of the game, e. g. the frequency of generated stimuli, to their capabilities and desired pace. The use of personalized tasks may also allow using the application in both,

initial and final phase of the exercises. Thanks to the use of virtual reality it is possible to personalize the application according to the age and condition of the patient. The simple interface and uncomplicated operating system will allow the game to be used by patients of any age.

2.2.2. Description of the created application

As part of the work, two applications were created using the Visual Studio environment and the Unity environment.

As part of the first application, the workshop scenery was prepared for men (Fig. 2.3). The scenery shows the actual conditions in the room, but with less detail. In front of the player there is a table with tools and shelves above it. The second application contains a scenery depicting a room equipped with a dressing table with various women's items such as lipstick or a brush (Fig. 2.4). It is dedicated to women and created in such a way that it resembles everyday life as much as possible.

The patient's task is to find the appropriate items and place them on the shelf according to clearly defined voice instructions. Both scenes in the applications have been selected in such a way that they are as close as possible to typical interests depending on gender. Thanks to the use of tasks similar to everyday activities, patients may feel more sense in carrying them out, because they are aware that they are doing something useful. A particle emitter is used to increase attention to the object and where it is to be placed. Thanks to this, the patient, apart from the voice message, receives an additional hint that allows him to notice objects on the omitted side. The places where the patient is to place the item have been deliberately placed in such a way that the patient has to make greater ranges of movement, which promotes his convalescence. The tasks proposed as part of rehabilitation were performed in such a way as to stimulate the neglected side to the maximum. In line with the previously mentioned assumptions, the player uses VR goggles to experience the feeling of being immersed in the virtual world as much as possible. The game also uses tasks similar to everyday activities, matched in terms of gender to the patient, and the entire scenery reflects the realism of the rooms on which it is modeled. The whole thing is accessible to patients from a different age group and easy to use.



Fig. 2.3. Scenery for men – a garage

Rys. 2.3. Sceneria dla mężczyzn – garaż



Fig. 2.4. Scenery for women – a dressing table

Rys. 2.4. Sceneria dla kobiet – toaletka

During the entire examination, the location of objects and the patient's head are recorded, as well as the time of performing the tasks. Thanks to this, it is possible to determine the speed of executing commands and the trajectory of movement of the head and hands. The obtained parameters make it possible to compare and evaluate the progress of rehabilitation.

2.3. Summary

Hemineglect syndrome is a neurological disorder which is a complication of brain stroke, significantly worsening the quality of patients' daily life. This disorder significantly affects the performance of even the simplest everyday activities, which is why it is so important to undertake appropriate rehabilitation.

There is a wide range of VR applications for people who have suffered ischemic strokes, but very few of them are intended directly for the rehabilitation of hemineglect syndrome. Moreover, the existing systems are dominated by the commercial aspect and are not sufficiently adapted to the needs of patients. There is a noticeable need to develop new rehabilitation methods, including those using VR technology - the advantages of such a solution include its mobility and the possibility of using it at home. When creating an application which supports the rehabilitation of HS, it is necessary to recognize the nature of the problem thoroughly. The specific symptoms of unilateral neglect require careful development of the app concept as well as its adaptation to patients' needs. Numerous research steps should also be undertaken. The application designed in this work can be further developed, and the next step will be to conduct measurements of upper limb kinematics and trunk as well as head orientation of healthy subjects. These examinations will be aimed at determining movement patterns so as to expand the possibilities of using the application towards supporting diagnostics of patients. Expanding the functionality of the software may also be positively influenced by increasing possibility of personalization, as well as extending it with new tasks and introducing a diagnostic element.

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Abstract

The hemineglect syndrome is a neurological disorder that affects mostly post-stroke patients. As a result of damage to the right brain hemisphere, the patient's perception of own body and environment on the left side becomes disturbed. It is especially important to introduce a multidisciplinary rehabilitation as soon as possible. Developing virtual technology may be helpful since it is able to provide a highly realistic scenery that will engage the patient to participate in therapy. The created application meets indications that have been carefully formulated, based on detailed literature data analysis.

Keywords: hemispacial neglect, virtual reality, rehabilitation, unilateral neglect, ischemic stroke.