Karolina ŁOPATA[1], Iga ZDANOWSKA[1], Magdalena LATOS[1],
Tomasz JASTRZĄB[*1,2] , Jagoda RÓŻYCKA[1,3], Agnieszka GORZKOWSKA[1,4]

Chapter 13. PROJEKTNEURO – A STEP TOWARDS EFFECTIVE PERSONALIZED THERAPY OF NEUROLOGICAL PATIENTS

13.1. Introduction

Therapy of neurological disorders poses a serious challenge to doctors, scientists, and patients. The challenge, especially in terms of post-stroke therapy and rehabilitation, will become even bigger in the future due to the demographic changes in Poland and Europe. As discussed in [1], we are faced with an unprecedented situation in which the age structure starts to reflect an inverted pyramid, meaning that the number of elderly people dominates over the younger ones. Due to this fact, it is predicted that the morbidity rates for strokes will increase in the nearest future. According to [2], in 2016, patients in Poland aged 54 and more, constituted over 80% of all the stroke cases treated both in hospitals and in outpatient treatment regardless of the place of living. Furthermore, the mortality rate within the group of patients aged 65+ was at the level of 84%. Based on Fig. 13.1 it can be observed that the number of patients in neurological or rehabilitation wards in Poland was slowly increasing over the years 2009-2019. Based on the statistics for year 2017 included in [3], it can be predicted that about 17% of all neurological patients suffered from strokes, with the mortality rate of 11%. The same study shows that only 15% of survivors were contracted for neurorehabilitation.

[1] Technicenter Sp. z o.o.
[*] Corresponding author: tomasz.jastrzab@polsl.pl, ul. Akademicka 16, 44-100 Gliwice, PL.
[2] Department of Algorithmics and Software, Silesian University of Technology.
[3] Institute of Psychology, Faculty of Social Science, University of Silesia.
[4] Department of Neurology, Medical University of Silesia.

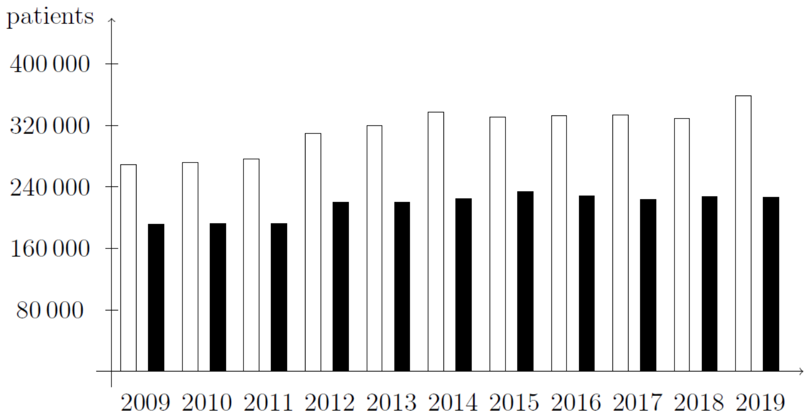

Fig. 13.1. The numbers of neurological (white) and rehabilitation ward patients in Poland in 2009-2019 (based on [4])
Rys. 13.1. Liczba pacjentów na oddziałach neurologicznych (biały) i rehabilitacyjnych w Polsce w latach 2009-2019 (opr. na podstawie [4])

Successful therapy of neurological disorders is essential for patient's health-related quality of life (HRQOL). HRQOL is a multi-dimensional concept that includes domains related to physical, mental, emotional, and social functioning [5]. These areas may be affected by the status of health. Thus, stroke has a short- and long-term impact on patients' life domains. Undergoing a stroke may have negative health, social, and economical effects [6]. In terms of health effects the stroke results in physical and/or mental disabilities, frequently affecting cognitive functions, speech or emotions. Disorders in these areas easily lead to social exclusion and deteriorated QOL, caused by the reduced ability to undertake professional and physical activities. These observations are also confirmed in [7], where patients report worse QOL after stroke than before the attack. This evaluation is positively correlated with the overall patient fitness, level of education (the higher the level, the better the self-assessed quality), marital status (married patients find their QOL better), and place of residence (patients living in urban areas perceive their QOL as better). The negative impact of craniocerebral injuries on the HRQOL is also pointed out in [8]. Although its assessment depends on the cause of the disorder, the overall QOL is considered worse.

Taking the above into account, it is clear that tools supporting effective therapy and rehabilitation of neurological patients are needed. It is also important that the tools not only help to reduce the deficits by regular brain training, they should also help to overcome the problems related to everyday activities [9]. Responding to this need, we present a tool that can be used for the therapy of neurological patients, especially suffering from post-stroke cognitive deficits. Let us note however, that the tool has a potential of being used for the therapy of, e.g., Alzheimer's disease or dementia.

Our contribution is the ProjektNeuro application aimed at the neuropsychological therapy of adults. The application aims to help in the rehabilitation of the following areas: executive functions, attention, visuospatial functions, and memory. In this paper, we present the assumptions made while developing the application and respective therapeutic tasks. We also point out the features which allow to personalize the therapy and adjust it to patient's needs. Since we also intend to scientifically confirm the efficiency of patient's therapy with the use of the designed application, we briefly describe the foundations of the clinical study being currently conducted in the University Clinical Center of the Medical University of Silesia in Katowice.

The paper is organized into 4 sections. In section 2, we briefly review the literature, focusing on the personalization aspects as well as the existing hardware and software-supported rehabilitation methods. In section 3, we describe the ProjektNeuro application the clinical study assumptions. Section 4 concludes the paper.

13.2. Related work

Personalized (precision) medicine is typically related to the analysis of genes and biomarkers, e.g., in the treatment of cancer. Such an analysis is also applicable in the field of neurological disorders treatment [10]. However, here we look at the personalized medicine from a different perspective. Namely, we focus on the individual features of each patient, as pointed out in [11]. The authors underline the influence of patients on their rehabilitation process, which should take into account their individual features. A similar suggestion, related to social inclusion support of people with disabilities, is also discussed in [12]. The author considers personalized therapy in the context of individual educational, professional, or development path planning. EEG signals or eye-tracking mechanisms are the sources of data for personalization. Personalized neuropsychology of children is studied in [13]. The authors discuss the pre-appointment assessment of the patients based on the information provided by their parents. Based on the collected data, the time and approach taken during the first meeting is decided individually for each patient. In [8] it is stated that a personal approach to each patient's difficulties and injuries may help in their return to normal, daily life. The neurorehabilitation which is fitted to the cognitive disorders' configuration will benefit in better adjustment level. The positive impact of personalized therapy as compared to “one-size-fits-all” therapy is also confirmed in the clinical study by Peretz et al. [14].

The authors consider the therapy of cognitive functions by comparing the use of standard computer games with the approach in which the games adapt themselves to the patient's progress. The latter approach turns out to be more efficient.

Successful therapy, either personalized or general, is often supported by specialized hardware or software solutions. The work by Semprini et al. [11] points out a few major groups of such solutions. The authors discuss the positive effects of using robotic devices (motor rehabilitation), non-invasive brain stimulation (cognitive functions) or neural interfaces (both motor and cognitive functions rehabilitation). Successful therapy of neurological disorders can also be achieved by using the Virtual Reality (VR) or Augmented Reality (AR) based solutions. These solutions can help with motor and cognitive functions rehabilitation, including post-stroke neurorehabilitation [15, 16]. The big advantage of VR-based therapy, especially in its immersive version, is that the patient gets a realistic feeling of performing different activities of daily living. Additionally, the VR devices allow to track and objectively assess the patient's progress. Such an information helps to make the therapy more personalized [15].

Finally, there are also commercial solutions such as RehaCom [17], CogniPlus [18], and Dr Neuronowski® [19]. RehaCom software allows to train executive and cognitive functions including attention, visuospatial functions, and memory. It adjusts the level of difficulty to patient's progress and enables post-training evaluation [17]. The main drawback of the solution is that it is equipped with a relatively large steering panel, which lowers the ability of rehabilitation for patients with reduced mobility. The CogniPlus system is similar in nature to the RehaCom solution. It also supports the training of the same cognitive functions and allows for automatic level adjustment. It is also equipped with a steering panel. The main difference stems from the fact that it is closely related to the Vienna Test System tool which supports patient diagnostics [18]. Dr Neuronowski® differs from the previous solutions in that it is based on the idea of neural clock, and focuses on the time aspect of the exercises. It does not support visuospatial functions training, and focuses primarily on speech disorder treatment (although support for cognitive functions is also available). Since it is available on tablets without additional steering equipment except for headphones, it is better suited for patients with reduced mobility, especially children.

13.3. ProjektNeuro overview

Our application focuses on the therapy and rehabilitation of executive and cognitive functions such as attention, visuospatial functions, and memory. Executive functions are responsible for self-regulation processes and the cognitive flexibility. Attention is a basic neuropsychological ability to process the information from the environment. Visuospatial functions are necessary to identify visual and spatial relationships among objects. Memory refers to the processes of acquiring, storage, retaining, and retrieving of the information. The reason for choosing these particular functions is that they constitute the typical areas affected by strokes [20]. Moreover, it has been shown in numerous clinical studies and literature reviews that there is some positive evidence that the neuropsychological interventions in these areas are helpful [21].

13.3.1. Application design

The ProjektNeuro application was developed with the aim of supporting adults with reduced mobility, therefore it is designed to run on 10-inch or larger tablets. The application is divided into four functional modules, corresponding to respective functions described before (cf. Fig. 13.2). Within each module one may find four varying tasks, each supporting different number and types of difficulty levels.

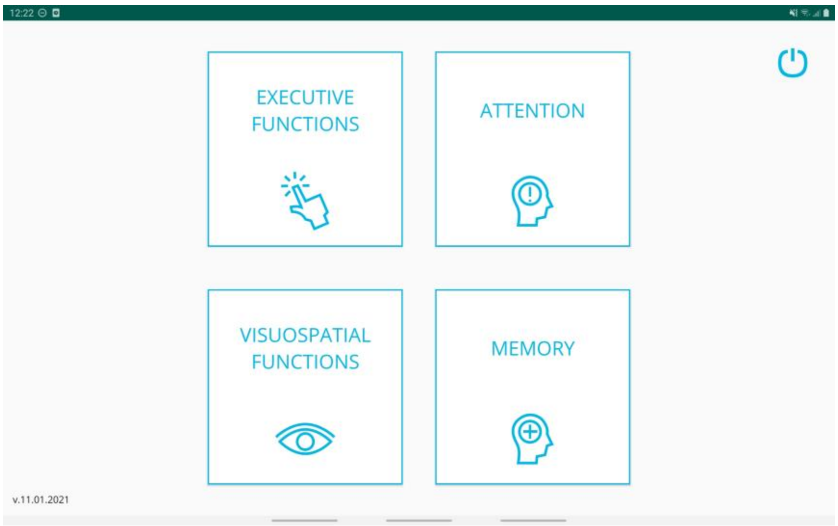

Fig. 13.2. ProjektNeuro modules
Rys. 13.2. Moduły aplikacji ProjektNeuro

Here we present a brief summary of the tasks in the respective modules:

1. Executive functions – the patient trains categorization and abstract thinking (by assigning products to proper baskets), real-life arithmetic (by paying appropriate amount of money, cf. Fig. 13.3), planning (by preparing meals according to given or self-designed recipes), and self-control (by repeatedly packing all products and later refraining from packing some of them).
2. Attention – the patient trains alertness, both visual and auditory (by reacting to different stimuli in the kitchen context, cf. Fig. 13.4, as well in the environment of, e.g. waiting room), selective attention (by admitting only chosen people through the door), and attention switching (by changing the focus from one stimulus to another).
3. Visuospatial functions – the patient trains visual synthesis and analysis capabilities (by combining small images into a single one, cf. Fig. 13.5, or doing the reverse), spatial orientation (by planning and following a route), and shape recognition (by finding a matching object by its shadow).
4. Memory – the patient trains operational (by remembering heard phone numbers) and direct memory, in an immediate and deferred setup, with different modalities of the stimuli (by remembering shown shopping list or heard story, or by identifying changes in a picture, cf. Fig. 13.6).

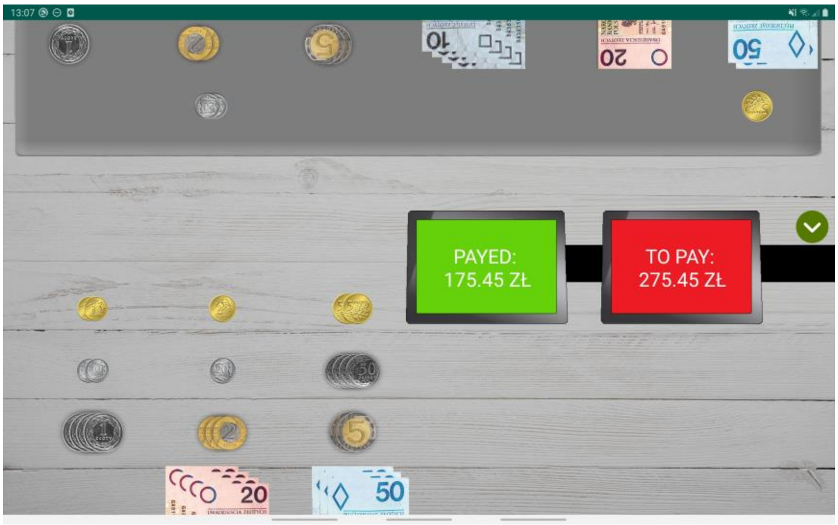

Fig. 13.3. Example Payment task setup (executive functions module). The patient is supposed to pay the given amount using available cash

Rys. 13.3. Przykład zadania pn. Płacenie (moduł funkcji wykonawczych). Pacjent ma za zadanie zapłacić określoną kwotę korzystając z dostępnych nominałów

Fig. 13.4. Example Cooking task setup (attention module). The patient is supposed to peel off the potato and react to cooking pot and kettle

Rys. 13.4. Przykład zadania pn. Gotowanie (moduł uwagi). Pacjent ma za zadanie obierać ziemniaka i reagować na gotujący się garnek i czajnik

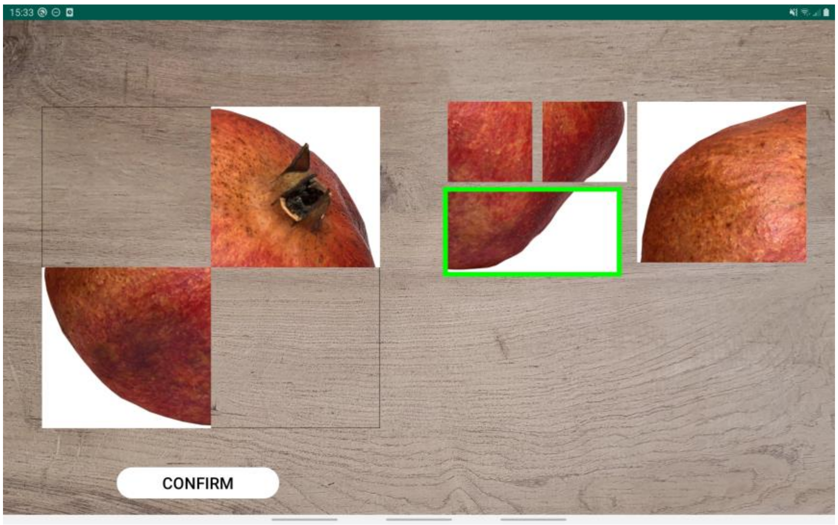

Fig. 13.5. Example Puzzle task setup (visuospatial functions module). The patient is supposed to combine smaller images into a single, larger one

Rys. 13.5. Przykład zadania pn. Układanka (moduł funkcji wzrokowo-przestrzennych). Pacjent ma za zadanie połączyć mniejsze obrazki w jeden, większy obraz

Fig. 13.6. Example Remember objects task setup (memory module). The patient is supposed to remember shown locations and then point the changed element
Rys. 13.6. Przykład zadania pn. Zapamiętaj elementy (moduł pamięci). Pacjent ma za zadanie zapamiętać pokazane lokalizacje, a następnie wskazać element, który uległ zmianie

In terms of therapy personalization, the application adapts itself to patient progress by automatically changing the difficulty level. Furthermore, it tracks various factors for each task, such as the number of correct/incorrect answers, reaction times, number of hints displayed, etc. The data is collected on the device and automatically uploaded to the server, where it can be analyzed by the person working with the patient. Since the therapists have the access to patient's data, they can effectively plan the next-day therapy, easily identifying the areas that require more intensive training.

13.3.2. Clinical study

In the clinical study, we focus on patients which suffered their first-ever stroke at most 3 months before the therapy and do not have the symptoms of aphasia, delirium, or depression, as well as at least one functional upper limb. Additionally, we require the patient to be present on the ward for at least 21 days.

We apply the pre-post methodology, meaning that the patient is tested using a battery of psychological tests (including MoCA attention subtest [22], selected RBANS subtests [23], CTT 1 & 2 [24], selected WAIS-R tests [25], and TUS subtest [26]) before and after the therapy. Based on pre-test results, the patients are assigned to work with a given module. Upon study completion, collected test results will be made subject to statistical analysis, supported by the analysis of data gathered during therapy. The aim is to confirm statistically significant improvement of patients' cognitive functions.

To give the reader a hint on the efficacy of the proposed therapy, we analyzed the changes in difficulty levels recorded by the tool. The best daily change was equal to +7, while the largest drop amounted to -4 levels. We observed some drops in 7 out of 16 modules, however, they constituted at most 17% of observed changes for a given task. We found out that the Cooking and Queue tasks (attention module) as well as the Labyrinths task (visuospatial functions module) were the hardest (the greatest number of drops, or the fewest increases). Overall, for almost 85% patient-task pairs we recorded net progress in difficulty level, while the remaining 15% stayed at the same level after the therapy.

13.4. Summary

In the paper, we presented a tool, called ProjektNeuro, supporting the therapy of neurological patients. Currently, the tool aims at helping the patients suffering from cognitive and executive functions disorders resulting from stroke. We presented the main features of the application, mentioning the possible personalization elements. We have also briefly outlined the presently conducted clinical study in which the application is used and hinted at some results of this study. We believe that the tool can play a significant role in improving the quality of life of patients suffering from post-stroke disorders, not only during the therapy in the hospital but also afterwards.

Acknowledgements

The research has been supported by the European Union under the Regional Operational Program of the Śląskie Voivodeship 2014-2020 within the project *Opracowanie innowacyjnych metod terapii neuropsychologicznej osób dorosłych* (“Development of innovative methods for the neuropsychological therapy of adults”) awarded to Technicenter Sp. z o.o.

Bibliography

1. J. Mazurek, A. Blaszkowska, J. Rymaszewska, Rehabilitacja po udarze mózgu – aktualne wytyczne, *Nowiny Lekarskie* (2013) **82(1)**:83-88.
2. Ministerstwo Zdrowia, Mapa potrzeb zdrowotnych w zakresie chorób układu nerwowego (neurologicznych wieku podeszłego) (2018).
3. Agencja Oceny Technologii Medycznych i Taryfikacji, Analiza organizacji udzielania świadczeń w zakresie rehabilitacji neurologicznej (2019).
4. Central Statistical Office of Poland, Local Data Bank: https://bdl.stat.gov.pl/, accessed 23 March, 2021.
5. G.H. Guyatt, D.H. Feeny, D.L. Patrick, Measuring Health-related quality of life, *Annals of Internal Medicine* (1993) **118(8)**:263-270.

A. Kłak, Następstwa udaru mózgu, In: F. Raciborski, M. Gujski (eds.): *Udary mózgu – rosnący problem w starzejącym się społeczeństwie*, 47-63, Instytut Ochrony Zdrowia, Warszawa (2016).

6. D. Kulina, A. Chomicka, W. Fidecki, M. Wysokiński, P. Chruściel, T. Zdanowicz, Ocena jakości życia pacjentów po udarze mózgu, *Pielęgniarstwo Neurologiczne i Neurochirugiczne* (2017) **6(4)**:163-169.
7. M. Pąchalska, *Rehabilitacja neuropsychologiczna*, UMCS, Lublin (2009).
8. Sarzyńska-Długosz, Rehabilitacja po udarze: https://www.infozdrowie.org/download/101/28317/4sarzynska.pdf, accessed: 23 March, 2021.
9. L. Tan, T. Jiang, L. Tan, J.-T. Yu, Toward precision medicine in neurological diseases, *Annals of Translational Medicine* (2016) **4(6)**:104.
10. M. Semprini, M. Laffranchi, V. Sanguineti, L. Avanzino, R. De Icco, L. De Michieli, M. Chiappalone, Technological Approaches for Neurorehabilitation: From Robotic Devices to Brain Stimulation and Beyond, *Frontiers in Neurology* (2018) **9**:212.
11. J. Zielińska, Sprofilowana i spersonalizowana terapia pobudzana (sterowana) danymi, *Niepełnosprawność – zagadnienia, problemy, rozwiązania* (2017) **23**:132-148.
12. T.A. Zabel, L.A. Jacobson, A.E. Pritchard, E.M. Mahone, L. Kalb, Pre-appointment online assessment of patient complexity: Towards a personalized model of neuropsychological assessment, *Child Neuropsychology* (2021) **27(2)**:232-250.
13. C. Peretz, A.D. Korczyn, E. Shatil, V. Aharonson, S. Birnboim, N. Giladi, Computer-Based, Personalized Cognitive Training versus Classical Computer Games: A Randomized Double-Blind Prospective Trial of Cognitive Stimulation, *Neuroepidemiology* (2011) **36**:91-99.

14. A. Stasieńko, I. Sarzyńska-Długosz, Zastosowanie rzeczywistości wirtualnej w rehabilitacji neurologicznej, *Postępy Rehabilitacji* (2016) **4**:67-75.
15. G. Riva, V. Mancuso, S. Cavedoni, Ch. Stramba-Badiale, Virtual reality in neurorehabilitation: a review of its effects on multiple cognitive domains, *Expert Review of Medical Devices* (2020) **17(10)**:1035-1061.
16. RehaCom, https://www.treningmozgu.pl/doc/metody/katalog_rehacom.pdf, accessed: 23 March, 2021.
17. CogniPlus, https://cognific.pl/produkt/cogniplus/, accessed: 23 March, 2021.
18. Dr Neuronowski®, https://neuronowski.com/, accessed: 23 March, 2021.
19. K. Kot-Bryćko, F. Pietraszkiewicz, Psychologia w medycynie. Część 2 – rehabilitacja neuropsychologiczna po udarze mózgu, *Medycyna Ogólna i Nauki o Zdrowiu* (2012) **12(4)**:344-347.
20. X.-D. Xu, H.-Y. Ren, R. Prakash, Vijayadas, R. Kumar, Outcomes of neuropsychological interventions of stroke, *Annals of Indian Academy of Neurology* (2013) **16(3)**:319-328.
21. Z.S. Nasreddine, N.A. Phillips, V. Bedirian, S. Charbonneau, V. Whitehead, I. Collin, J.L. Cummings, H. Chertkow, The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment, *Journal of the American Geriatrics Society* (2005) **53(4)**:695–699.
22. C. Randolph, M.C. Tierney, E. Mohr, T.N. Chase, The Repeatable Battery for the Assessment of Neuropsychological Status (RBANS): preliminary clinical validity, *Journal of Clinical and Experimental Neuropsychology* (1998) **20(3)**:310–319.
23. L.F. D'Elia, P. Satz, C.L. Uchiyama, T. White, *Color Trails Test. Professional manual*, Psychological Assessment Resources, Odessa, FL (1996).
24. J. Brzeziński, M. Gaul, E. Hornowska, A. Jaworowska, A. Machowski, M. Zakrzewska, *WAIS-R (PL) – Skala Inteligencji Wechslera dla Dorosłych – Wersja Zrewidowana. Renormalizacja 2004*, Pracownia Testów Psychologicznych Polskiego Towarzystwa Psychologicznego, Warszawa (2004).
25. A. Ciechanowicz, J. Stańczak, *TUS – Testy Uwagi i Spostrzegawczości*, Pracownia Testów Psychologicznych Polskiego Towarzystwa Psychologicznego, Warszawa (2006).

PROJEKTNEURO – A STEP TOWARDS EFFECTIVE PERSONALIZED THERAPY OF NEUROLOGICAL PATIENTS

Abstract

Personalized therapy and rehabilitation of post-stroke deficits is an important factor influencing patient's quality of life. The process can be greatly aided by using the advancements of information technology. In the paper, we present a novel tool supporting the therapy of adults, suffering from deficits in the areas of executive and visuospatial functions, attention, and memory. We describe selected elements of the application, mentioning the aspects of therapy personalization. We also outline the assumptions of the clinical study being conducted using this application.

Keywords: neuropsychology, neurorehabilitation, stroke, personalized therapy.