http://doi.org/10.35784/iapgos.8811

received: 25.11.2025 | revised: 14.12.2025 | accepted: 17.12.2025 | available online: 20.12.2025

COMPUTER SYSTEM FOR DIAGNOSTIC AND TREATMENT OF UNILATERAL NEGLECT SYNDROME

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Abstract. *Unilateral Spatial Neglect (USN) is a neuropsychological disorder commonly resulting from right hemisphere brain damage, leading to impaired awareness of stimuli on the left side of space. It significantly affects patient autonomy and rehabilitation outcomes. Traditional therapies such as Visual Scanning Training (VST) and Prism Adaptation (PA) lack standardization and objective diagnostic tools. This paper presents a computer-based system designed to support both diagnosis and therapy of USN. The system uses a 5-meter LED strip to deliver spatially distributed visual stimuli and records patient responses via a physical button. Reaction times and detection data are stored in a local database, enabling objective assessment and personalized therapy planning. The system architecture is modular, based on Clean Architecture principles, and implemented in C++20 on a Raspberry Pi 5 microcomputer. The graphical interface is built using GTKmm 4.0. Therapy sessions follow VST methodology. They include tracking moving stimuli, using visual anchors, and increasing stimulus density. Preliminary trials confirm the system's ability to differentiate neglect symptoms and support individualized therapy. Its portability, modularity, and integration of diagnostic and therapeutic functions make it a promising tool for clinical neurorehabilitation. Further validation and development are planned to support broader clinical adoption.*

Keywords: unilateral neglect syndrome, neuropsychology, medical device

SYSTEM KOMPUTEROWY DO DIAGNOSTYKI I TERAPII POMIJANIA STRONNEGO

Streszczenie. *Pomijanie stronne (USN) to zaburzenie neuropsychologiczne, które najczęściej występuje po uszkodzeniu prawej półkuli mózgu i prowadzi do braku świadomości bodźców po lewej stronie przestrzeni. Znacząco wpływa na samodzielność pacjenta oraz efektywność rehabilitacji. Tradycyjne metody terapii, takie jak trening skanowania wzrokowego (VST) czy adaptacja pryzmatyczna (PA), często nie są wystandaryzowane i nie oferują obiektywnych narzędzi diagnostycznych. W artykule przedstawiono komputerowy system wspomagający diagnozę i terapię USN. System wykorzystuje 5-metrową taśmę LED do prezentacji bodźców wzrokowych w różnych lokalizacjach przestrzennych, a reakcje pacjenta rejestrowane są za pomocą fizycznego przycisku. Czas reakcji i dane o wykryciu bodźców są zapisywane w lokalnej bazie danych, co umożliwia obiektywną ocenę i indywidualne planowanie terapii. Architektura systemu jest modułowa, oparta na zasadach Clean Architecture, zaimplementowana w języku C++20 na mikrokomputerze Raspberry Pi 5. Interfejs graficzny został zbudowany z użyciem biblioteki GTKmm 4.0. Sesje terapeutyczne bazują na metodologii VST, obejmując śledzenie ruchomych bodźców, wykorzystanie punktów odniesienia oraz zwiększanie gęstości bodźców. Wstępne badania potwierdziły skuteczność systemu w rozpoznawaniu objawów pomijania i wspieraniu terapii. Jego mobilność, modułowość i integracja funkcji diagnostycznych i terapeutycznych czynią go obiecującym narzędziem w neurorehabilitacji klinicznej.*

Słowa kluczowe: pomijanie stronne, neuropsychologia, urządzenie medyczne

Introduction

Unilateral spatial neglect (USN), also known as hemispatial neglect syndrome, is a cognitive disorder characterized by limited attention or activities directed at stimuli in the space contralateral to the lesion. It is diagnosed when the patient's functional difficulties cannot be explained in terms of underlying sensory-motor deficits [1]. "It may manifest itself in various perceptual modalities (visual, auditory, sensory) and/or motor activity, concern the reception and response to real stimuli or the creation of visual images, and also be expressed in various scopes and frames of spatial references" [6, 10, 15, 17]. The most common cause of USN is extensive hemispheric lesions (usually post-stroke, but may also be traumatic or hyperplastic) involving the posterior parietal areas, responsible for the integration of sensory information and its spatial analysis, essential for directing attention, understanding relationships between objects, and programming movement [2, 11, 16]. Involvement of the inferior parietal lobule or the adjacent temporoparietal junction is considered critical for USN, but frontal and subcortical lesions (thalamus, basal ganglia) [3] and hemispheric activation disorders [7] also contribute to its pathogenesis. Unilateral spatial neglect is a clinically diverse syndrome, encompassing various variants, types, symptom presentations, and degrees of severity. A rare and usually mild form of the syndrome is right-sided neglect, caused by damage to the left hemisphere of the brain. Its symptoms are primarily observed in the early stages of stroke and usually resolve spontaneously [6, 13]. The most common and severe is the left-sided variant, also known as visuospatial neglect, characterized by neglect of the left side of space following damage to the right hemisphere of the brain. It manifests primarily in the visual modality and is usually accompanied by a lack of awareness of the deficit [15]. The primary cognitive pathophysiology is believed to be 1an abnormal distribution of visual attention to stimuli in space. Patients with this disorder appear as if something "magnetically" draws their attention to the right side and prevents it from freely redirecting to the left [15, 17]. It is estimated to occur in half of patients in the acute phase of stroke and in approximately 20% of patients assessed three months later [12]. Across Europe, approximately one million such incidents are diagnosed each year [5, 8]. The consequences constitute an extremely serious health problem. It is also a significant social issue, as it requires specialized long-term care and significant financial outlays for the rehabilitation and care of those affected.

Table 1. Comparison of therapeutic methods for USN [8, 10, 11, 15]

Method	Mechanism of Action	Disadvantages
Prism Adaptation (PA)	Shifts visual field toward neglected side using prism glasses; promotes sensorimotor adaptation.	Short-term effects; discomfort for some patients; requires precise fitting and supervision.
Visual Scanning Training (VST)	Trains conscious shifting of gaze and attention toward neglected side using visual cues and anchors.	Requires high engagement and repetition; less effective in severe cases; motivation may be an issue.
Optokinetic Stimulation (OKS)	Uses moving visual stimuli to stimulate tracking toward neglected side, enhancing spatial activation.	Experimental; limited availability; less effective for patients with visual or attentional deficits.
Limb Activation Treatment (LAT)	Activates motor areas by moving limbs on neglected side, supporting spatial attention integration.	Depends on motor ability; not suitable for paralyzed patients; requires precise therapeutic guidance.
VR / Immersive Technologies	Engages patients in spatial tasks using virtual environments and multisensory stimuli.	High cost; limited access; requires specialized setup; lacks extensive clinical validation.

Table 1 summarizes the methods of diagnosis and therapy of USN including their mechanisms and disadvantages. Prism Adaptation (PA) and Visual Scanning Training (VST) are among the most commonly used and well-documented approaches. While PA works through sensorimotor adaptation, altering spatial perception, VST focuses on consciously shifting visual attention to the neglected side. Optokinetic Stimulation (OKS) and Limb

Activation Treatment (LAT) engage the visual and motor systems, respectively, stimulating activity on the neglected side. Virtual Reality (VR) therapies offer immersive multisensory environments that can enhance patient engagement, although they are still in the research phase. Each method has a different mechanism of action, allowing for complementary applications depending on the patient's needs.

It should be emphasized that these methods, especially those based on modern information technology, are not widely available and are still in the early stages of testing. There are also no universally accepted diagnostic and therapeutic procedures based on them.

1. Visual scanning training (VST)

Left-sided visuospatial neglect, commonly known as visual neglect, is a variant of neglect syndrome that most often requires neuropsychological therapy. The standard therapeutic approach for patients with this type of neglect is individual, behavioural visual scanning training (VST), also known as visual exploration therapy [15]. The premise of VST is to, after explaining to the patient their lack of spontaneous leftward gaze, teach them to actively direct their gaze to the neglected side of space until they develop a habit of this response. This method requires the patient to track the movement of visual stimuli, such as sequentially lit lights on a scanning board or objects moving on a computer screen. Training can also be combined with other skills, such as reading or writing, or other visuospatial tasks. The most important thing to remember during the exercises is to consider training principles, which include: the use of landmarks placed on the left side of the visual field (so-called anchors) to help locate the missed part of the image; the use of cues that draw attention to the left side of the space (e.g., a flickering light, a moving point), and stimuli density (introducing an increasing number of visual targets). This requires multiple repetitions of both the instructions and the response itself. The various devices presented in the literature used in VST training are largely created by therapists and are experimental in nature [15].

Despite its proven effectiveness, VST lacks standardized therapeutic protocols, which can lead to variability in outcomes across clinical settings.

The analysis of the limitations of currently used methods and devices indicates the need to develop modern technological solutions that could significantly support the diagnosis and treatment of UNS especially in cases where the clinical examination revealed visuospatial neglect [11]. Integrating VST into computer-based systems offers a promising solution. It enables objective measurement of patient responses and ensures consistent delivery of stimuli. This approach also supports personalized therapy planning. Moreover, such systems can enhance patient engagement and facilitate remote rehabilitation [14], addressing common limitations of traditional VST approaches.

2. UNS diagnostic and therapy system

The system's goal is to assess the patient's visual field by analyzing their reaction to light emitted by an LED strip and recording their response time using a physical button.

Visual stimuli are presented in various spatial locations, and the patient's task is to press the button when they perceive the light. These responses are interpreted as confirmation of their visual perception of a given area of the visual field.

The prototype layout of the diagnostic station, including the arrangement of the 5-meter LED strip, the position of the patient and therapist, the control button, and the LED lighting directions, is shown in Fig. 1. The distance of the patient from the LED strip is approximately 2 m, which ensures an even field of view and safe exposure to light stimuli.

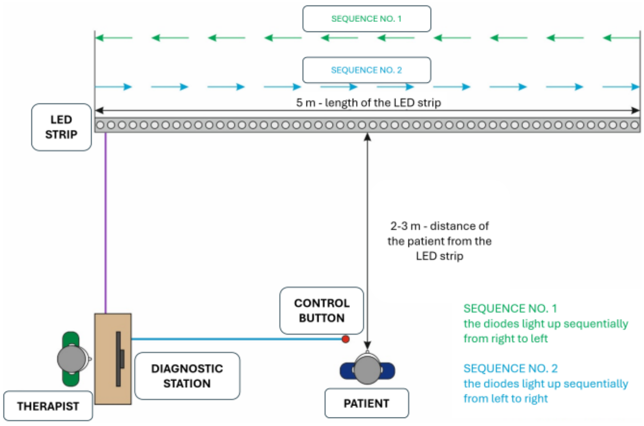

Fig. 1. USN diagnostic and treatment station

The hardware and software architecture of the designed diagnostic and therapeutic system is shown in Fig. 2. It is based on three functional layers:

- hardware,
- application logical layer,
- application user interface layer (GUI).

This separation enables a clear separation of responsibilities between components, increased testability, and compliance with Clean Architecture principles [9], including:

- Single Responsibility Principle (SRP) [4, 9]: Each part of the system has one clear job, making it easier to update without affecting other parts.
- Dependency Inversion Principle (DIP) [4, 9]: High-level logic does not depend directly on hardware details; instead, both rely on common interfaces. This makes the system flexible and easier to extend.

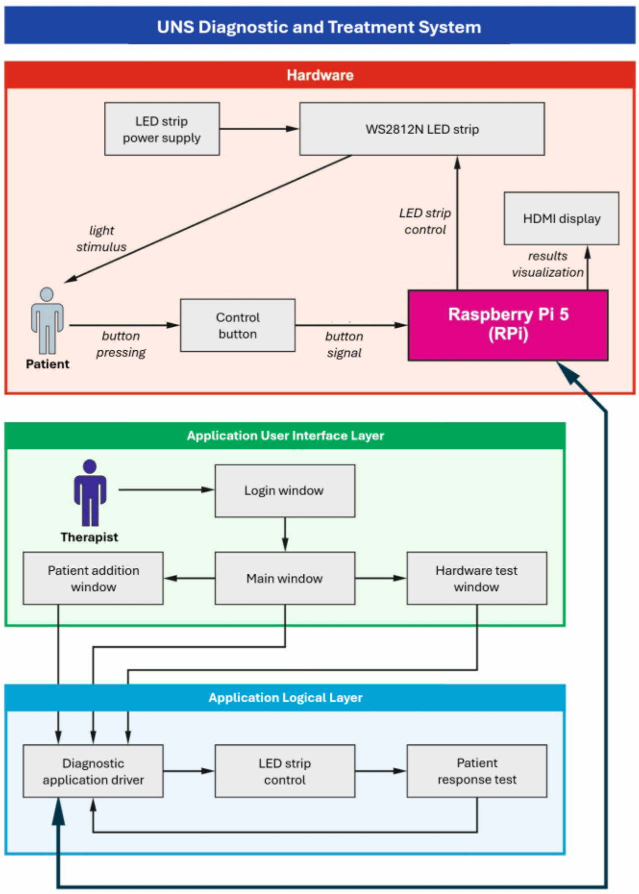

Fig. 2. Block diagram of the UNS diagnostic and therapeutic system

The system was implemented using a Raspberry Pi 5 Model B Rev 1.1 microcomputer [19] equipped with a quad-core ARM Cortex-A76 processor (2.4 GHz) and 8 GB LPDDR4X RAM running Raspberry Pi OS 12 (Bookworm) [20].

Fig. 3 shows the connection diagram of the Raspberry Pi 5 system, the WS2812B strip, the button and the POS-50-5-C2 (5V/50W) power supply.

Communication with the WS2812B LED strip was achieved via the SPI (Serial Peripheral Interface). Therefore, a proprietary SPI software driver was developed, which generates a signal compliant with the WS2812B protocol [23].

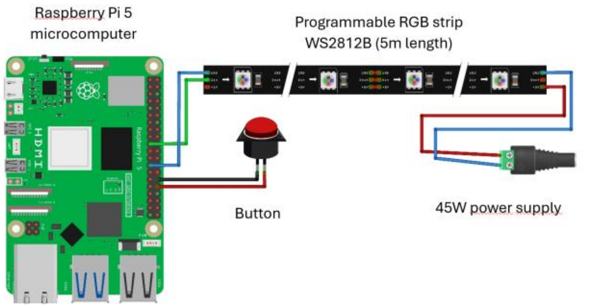

Fig. 3. Connection diagram of the Raspberry Pi 5 system, WS2812B ribbon cable, button and POS-50-5-C2 power supply

The project was implemented in C++20, adhering to the principles of clean code and a modular system architecture [9]. The system structure is divided into modules communicating via well-defined interfaces, supporting testability and layer independence. Design oriented towards separation of layers and stable interfaces facilitates software maintenance and development [9, 18].

The user interface was designed based on the Model–View–Presenter architecture, which allows for the separation of the visual portion of the program from its operation. The graphical portion of the system was implemented using the GTKmm 4.0 library [21], adapted to the C++ language. This solution is consistent with the principles of clean architecture [9] and embedded systems design [18], promoting further development and facilitating integration with other system modules.

To minimize jitter and ensure reaction time accuracy below 10 ms, the system employed several real-time optimization techniques. Critical threads responsible for stimulus presentation and input capture were assigned real-time priorities using FIFO scheduling policy [18], reducing latency from context switching. Reaction times were measured with high-resolution steady clocks in C++20, providing nanosecond precision and immunity to system clock drift. The custom software SPI driver for WS2812B LEDs utilized tight timing loops and DMA (Direct Memory Access) buffering, ensuring stable signal generation without timing drift. Additionally, interrupt-driven GPIO (General-Purpose Input/Output) handling [19] replaced polling for button presses, guaranteeing immediate event capture and consistent timing performance under Raspberry Pi OS.

Response results, along with patient data, are stored in a local SQLite database [22]. The collected data enables subsequent analysis of the collected material for diagnostic purposes and allows for the assessment of the effectiveness of the therapy.

The implemented system constitutes a fully functional prototype supporting the diagnosis and treatment of unilateral spatial neglect.

3. Preliminary clinical trials

Based on the implemented system, the following structured procedure is proposed for the diagnosis and therapy of Unilateral Spatial Neglect:

1) Initial Clinical Assessment – Patients are first evaluated by a neuropsychologist or rehabilitation specialist using standard neuropsychological tests (e.g., line bisection, clock drawing, reading tasks) to confirm the presence and severity of USN.
2) Computer-Aided Diagnosis – The patient is seated approximately 2 meters from a 5-meter LED strip. Visual stimuli are presented at various spatial locations. The patient is instructed to press a button upon perceiving the light. Reaction times and stimulus detection are recorded and stored in a local database for analysis.
3) Visual Scanning Training (VST) Therapy – Therapy sessions involve training the patient to consciously direct their gaze toward the neglected side. This includes:
   - Tracking moving visual stimuli.
   - Using visual anchors and attention cues.
   - Increasing stimulus density.
   - Integrating tasks such as reading and writing.
4) Monitoring and Adaptation – Therapy progress is monitored through repeated diagnostic sessions. Data analysis enables individualized therapy planning and adjustment of stimulus parameters. The system's modularity allows for future integration of auditory stimuli.
5) Final Evaluation and Recommendations – Post-therapy assessments are conducted to evaluate improvements. Patients may be advised to continue exercises at home and attend follow-up evaluations.

This procedure supports standardized therapy planning and enables objective measurement of therapeutic effectiveness.

The preliminary evaluation of the proposed diagnostic and therapeutic system was conducted on a pilot group of 10 participants. The age range was 50–75 years. The participants included members of the research team and were of both sexes. The group consisted of 8 neurologically healthy individuals as well as 2 patients who had experienced a right-hemisphere stroke and were clinically diagnosed with visuospatial neglect.

Participants underwent diagnostic sessions using the LED-based visual stimulation setup, followed by therapeutic exercises based on Visual Scanning Training (VST).

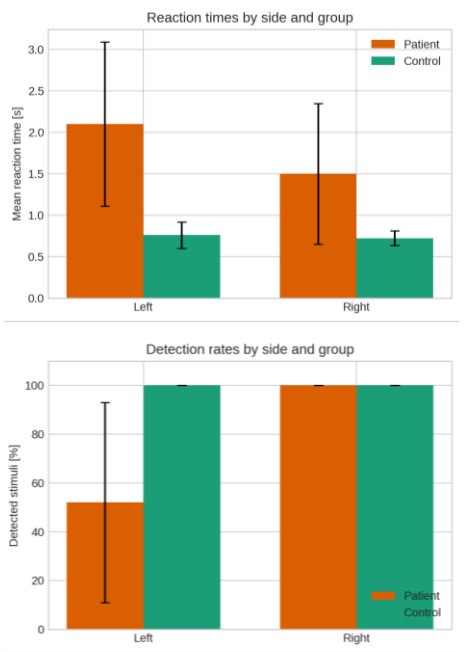

Fig. 4. Objective measures from preliminary clinical trials (patients n = 2; controls n = 8). Top: mean reaction time (s) with SD by side and group. Bottom: mean detection rate (%) with SD by side and group. Patients show slowed responses and reduced detection on the left with preserved right-side performance

Initial observations indicated that the system successfully differentiated between individuals with and without neglect symptoms. The obtained results are presented in Fig. 4. Compared with controls, patients exhibited markedly prolonged reaction times and reduced stimulus detection on the left side (left RT ≈ 2.10 s vs 0.76 s; left detection ≈ 52% vs 100%), while right-side performance remained intact (100% detection; near-normal RT). These patterns are consistent with left-sided visuospatial neglect.

These promising results suggest that the developed device has the potential to become a valuable tool in clinical neurorehabilitation. Its ability to provide objective measurements, support personalized therapy, and integrate diagnostic and therapeutic functions in a single platform makes it a strong candidate for routine use in rehabilitation settings.

This small-scale study was intended as a proof-of-concept to assess system usability and feasibility before initiating large-scale trials. Including a larger and more diverse population in future studies is essential to validate the effectiveness and generalizability of the proposed system. Stroke-related unilateral neglect presents with considerable variability depending on lesion location, severity, and recovery phase. Patients in the acute, subacute, and chronic stages may respond differently to visual scanning therapy, and those with mild versus severe neglect require tailored intervention strategies. Expanding the sample to include individuals with different stroke etiologies (ischemic and hemorrhagic), comorbid motor or cognitive impairments, and a broader age range will ensure that the system is tested under clinically relevant conditions. Furthermore, multicenter recruitment will enhance demographic diversity and external validity, supporting the development of standardized therapeutic protocols and facilitating regulatory approval for clinical use. These studies will be initiated following the acquisition of all necessary ethical approvals and regulatory permissions.

4. Summary

The proposed diagnostic and therapeutic system for unilateral spatial neglect offers several advantages over traditional methods:

1) Objective Diagnosis – The system records precise reaction times and stimulus detection data, enabling quantifiable and reproducible assessment of neglected visual fields.
2) Modular Architecture – Built using clean architecture principles, the system allows for easy expansion and integration of additional modules, such as auditory stimuli, enhancing its diagnostic and therapeutic capabilities.
3) Personalized Therapy – Therapy sessions can be tailored to individual patient needs based on performance data, allowing for dynamic adjustment of stimulus parameters and therapy intensity.
4) Portability – The system is mobile and can be used in various settings, including clinics, rehabilitation centers, and patient homes, making it accessible to patients with limited mobility.
5) Integrated Diagnosis and Therapy – Combines diagnostic functionality with Visual Scanning Training (VST), streamlining the therapeutic process and reducing the need for multiple devices or separate sessions.
6) Enhanced Engagement and Feedback – Interactive visual stimuli and immediate feedback mechanisms increase patient engagement and reinforce correct responses, contributing to more effective therapy.
7) Data Storage and Analysis – Patient data is stored in a local SQLite database, enabling longitudinal tracking of therapy outcomes and statistical evaluation of therapeutic effectiveness.
8) Standardization Potential – The system supports the development of standardized therapeutic protocols and facilitates comparison of results across patients and institutions.

While the proposed system offers several advantages, certain limitations should be acknowledged:

1) Dependence on motor ability – The system requires patients to press a physical button to confirm stimulus detection. This may be challenging for individuals with severe motor impairments or hemiparesis.
2) Visual constraints – The LED-based stimuli may be less visible in environments with strong ambient light, potentially reducing diagnostic accuracy.
3) Limited sensory modalities – Current implementation focuses on visual stimuli only; patients with combined sensory deficits may require multimodal approaches.
4) Small sample size in preliminary trials – Initial evaluation involved a limited number of participants, which restricts generalizability.
5) Hardware setup requirements – Although portable, the system still requires physical installation and may not be suitable for all home environments without assistance.

To ensure the proposed system can be successfully implemented in clinical practice, several key areas require further development and validation.

The preliminary trials described in this paper were conducted as internal usability and feasibility tests with voluntary participants, including members of the research team and stroke patients under clinical supervision. These tests did not involve invasive procedures and were performed in compliance with institutional guidelines.

Expanded clinical trials are essential to confirm the system's effectiveness across a broader and more diverse patient population. These studies should include individuals with various neurological conditions and be conducted in multiple clinical settings to ensure generalizability. Formal ethical approval for large-scale clinical trials is currently in progress and will be obtained from the appropriate Bioethics Committee before enrolling additional patients.

Ethical and regulatory approvals must be obtained to comply with medical standards and ensure patient safety. This includes certification as a medical device and adherence to data protection regulations.

Usability testing should be conducted to optimize the system for patients with different cognitive and physical abilities. Enhancements to the user interface and interaction methods may be necessary to improve accessibility. The system accommodates these needs through several design features:

- Large, high-contrast buttons for easy visibility and interaction, reducing the risk of missed inputs.
- Minimal text and clear icons to support patients with attention or language difficulties.
- Voice prompts and auditory feedback to guide users through tasks without relying solely on visual cues.
- Simple navigation flow with limited steps to avoid cognitive overload.
- Adjustable stimulus speed and density so therapists can tailor sessions to individual capabilities.

Future development will also consider integration with widely used medical data exchange standards such as HL7 and FHIR. These standards enable secure and interoperable communication with hospital information systems and electronic health records, which will increase the practical value of the system and facilitate its adoption in clinical workflows. This involves developing protocols for use in rehabilitation centers and training medical personnel in system operation and data interpretation.

Software optimization is needed to ensure stability, responsiveness, and compatibility with various hardware platforms. Improvements in performance and reliability will support long-term use.

Data security must be addressed through robust encryption and secure storage solutions, ensuring compliance with privacy laws such as GDPR.

Remote therapy capabilities should be developed to support telemedicine applications, allowing patients to receive therapy at home under professional supervision.

Finally, commercialization efforts should include documentation, training materials, and partnerships with healthcare providers to facilitate widespread adoption.

The developed computer system provides an innovative and effective tool for diagnosing and treating unilateral spatial neglect by combining objective measurements with neuropsychological therapy. Initial clinical trials confirmed its ability to differentiate neglect symptoms and support personalized therapy. Its modular architecture and portability make it suitable for both clinical and home use. Further development and validation are necessary to ensure its integration into routine neurorehabilitation practice.

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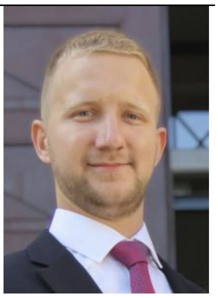

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