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EFFECTIVENESS OF VR THERAPY USING THE VRNOW SIMULATOR FOR PHANTOM LIMB PAIN FOLLOWING LOWER LIMB AMPUTATION

ЕФЕКТИВНІСТЬ VR-ТЕРАПІЇ ІЗ ВИКОРИСТАННЯМ ТРЕНАЖЕРА VRNOW ПРИ ФАНТОМНИХ БОЛЯХ ПІСЛЯ АМПУТАЦІЇ НИЖНЬОЇ КІНЦІВКИ

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Abstracts

Under conditions of martial law in Ukraine, a marked increase in the incidence of traumatic amputations has been observed, which highlights the urgent need for effective rehabilitation strategies. Military amputees, despite their high motivation to return to an active and meaningful life, frequently experience pronounced pain syndromes, including residual limb pain and phantom limb pain. The intensity and chronicity of pain may substantially limit physical activity, hinder prosthetic training, and adversely affect psycho-emotional well-being. In this context, effective pain management constitutes a key prerequisite for successful rehabilitation, as pain reduction provides the foundation for functional recovery and reintegration into an active lifestyle. Mirror therapy demonstrates limited clinical effectiveness and is associated with a number of anatomical and motivational barriers. Virtual reality is therefore considered an alternative approach to sensorimotor reintegration, offering enhanced feedback and improved patient compliance. Accordingly, investigation of the effectiveness of VR therapy represents a timely and well-justified direction in contemporary rehabilitation science.

The objective of the study is to demonstrate the effectiveness of VR therapy using the VRNOW simulator in the management of phantom limb pain in patients following lower limb amputation.

Materials and Methods. The study was conducted at the Medical Centre “Path to Health” LLC during 2024–2025 and consisted of two 14-day treatment courses. A total of 36 patients after lower limb amputation participated in the study during the third (pre-prosthetic rehabilitation) and fourth (prosthetic rehabilitation) stages of the rehabilitation process. The mean age of the male participants was 41,2±8 years; all patients were military personnel. Transtibial amputations accounted for 63,9% (n=23) of cases, while transfemoral amputations accounted for 36,1% (n=13). Phantom pain dynamics and quality of life were assessed using the Phantom and Stump Pain Questionnaire (PSPQ), the SF-36 Health Survey, and a pain diary. VR therapy using the VRNOW simulator was administered twice daily, with session durations of 20-30 minutes during Stage III and 35-45 minutes during Stage IV, based on an individualised selection of virtual tasks.

Results. VR therapy resulted in clinically significant improvements across multiple pain parameters. According to the PSPQ (NRS index), the number of patients with moderate residual limb pain decreased from 22 to 6, while 33,3% of patients (n=12) reported complete pain relief (mean score 1,83±0,28; $p \leq 0,001$). A substantial reduction was also observed in the number of patients with persistent phantom limb pain (from 30 to 8), with complete pain resolution reported in 44,4% of cases (n=16; mean score 1,44±0,28; $p \leq 0,001$). In addition, a marked decrease in persistent phantom sensations was noted, along with the disappearance of intrusive symptoms. Statistically significant improvements were recorded in most SF-36 domains, with the greatest increase observed in the bodily pain scale (BP +28,4 points; $p \leq 0,001$), confirming a pronounced analgesic effect. The increase in the Global Health Index (GHI +12,0 points; $p \leq 0,01$) reflects a clinically meaningful transition to a higher level of functioning.

Conclusions. The use of VR therapy with the VRNOW simulator in patients after lower limb amputation contributes to the reduction of residual limb pain, phantom limb pain, and phantom sensations through staged sensorimotor stimulation and restoration of neural connections. During Stage III (pre-prosthetic rehabilitation), the application of the Virtual Limb mode, isometric exercises, and virtual interaction with objects facilitates the formation of controlled visuomotor feedback, resulting in reduced pain intensity, attenuation of phantom sensations, and normalisation of perception of the missing limb. During Stage IV (prosthetic rehabilitation), the therapeutic focus shifts towards the restoration of proprioception, gait symmetry, and dynamic balance, which collectively enhance functional capacity and improve quality of life in patients after lower limb amputation.

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В умовах воєнного стану в Україні спостерігається зростання частоти травматичних ампутацій, що актуалізує проблему ефективної реабілітації. Військові ампутанти, попри високу мотивацію до повернення до активного та повноцінного життя, часто стикаються з вираженими больовими проявами, зокрема болем у куксі та фантомним болем. Інтенсивність і хронізація больового синдрому можуть суттєво обмежувати фізичну активність, ускладнювати опанування протеза та негативно впливати на психоемоційний стан. У цьому контексті ефективний менеджмент болю є ключовою умовою успішної реабілітації, оскільки саме зменшення больових відчуттів створює підґрунтя для відновлення функціональності та повернення до максимально активного способу життя. Дзеркальна терапія демонструє обмежену клінічну результативність і має низку анатомічних та мотиваційних бар'єрів. Віртуальна реальність розглядається як альтернативний метод сенсомоторної реінтеграції, що забезпечує розширений зворотний зв'язок і підвищує комплаєнс. Дослідження ефективності VR-терапії є обґрунтованим і своєчасним напрямом сучасної реабілітології.

Мета дослідження полягає у доведенні ефективності VR-терапії із використанням тренажера VRNOW при фантомних болях у пацієнтів після ампутації нижньої кінцівки.

Матеріали та методи. Дослідження було проведено на базі ТОВ «Медичний центр «Шлях до здоров'я» у період 2024/2025 років. Воно складалося з двох курсів по 14 днів. У дослідженні взяли участь 36 пацієнтів після ампутації нижньої кінцівки, які перебували на третьому «допротезна реабілітація» та четвертому «протезування» етапах реабілітації. Середній вік чоловіків становив 41,2±8 років. Частка військових після ампутації складала 100% (n=36). Серед них транстібіальний рівень ампутації виконано у 63,9% (n=23) пацієнтів, а трансфеморальний – 36,1% (n=13). Для оцінки динаміки фантомного болю та якості життя використано шкалу PSPQ, опитувальник SF-36 та щоденник болю. VR-терапія із використанням тренажера VRNOW застосовувалася 2 рази на день по 20-30 хв занять на III етапі реабілітації та 35-45 хв на IV етапі реабілітації і передбачала індивідуалізований підбір віртуальних завдань.

Результати дослідження. Проведена VR-терапія дозволила досягти клінічно значущих змін різних проявів болю. За шкалою PSPQ у контексті показника NRS скоротилася кількість пацієнтів із помірним болем у куксі з 22 до 6 осіб, а 33,3% осіб (n=12) відзначили повну відсутність болю (середній показник склав 1,83±0,28 балів (p≤0,001). Відзначено значне зменшення пацієнтів (з 30 до 8 осіб) із постійним фантомним болем, а у 44,4% осіб (n=16) біль повністю зник (середній показник склав 1,44±0,28 балів (p≤0,001). Також спостерігалося помітне зменшення (з 28 до 6 осіб) постійних фантомних відчуттів у пацієнтів та зникнення нав'язливих проявів. Відбулося статистично значуще покращення більшості показників за опитувальником SF-36, де найбільший приріст відзначено за шкалою болю (BP +28,4 бали; p≤0,001), що підтверджує чіткий анальгетичний ефект. Приріст загального індексу якості життя (GHI +12,0 балів; p≤0,01) відображає клінічно значущий перехід до вищого рівня функціонування.

Висновки. Застосування VR-терапії із використанням тренажера VRNOW для пацієнтів після ампутації нижньої кінцівки сприяє зменшенню болю у куксі, фантомного болю та фантомних відчуттів шляхом поетапної сенсомоторної стимуляції й відновлення нейронних зв'язків. На III етапі (допротезна реабілітація) використання режиму Virtual Limb, ізометричних вправ і віртуальної взаємодії з об'єктами допомагає сформувати контрольований візуально-моторний зворотній зв'язок. Завдяки цьому знижується інтенсивність болю, фантомних відчуттів і нормалізується сприйняття втраченої кінцівки. На IV етапі (протезування) акцент переноситься на відновлення пропріорецепції, симетрії ходи та динамічного балансу, що в сукупності підвищує функціональну спроможність і якість життя пацієнтів після ампутації нижньої кінцівки.

Ключові слова: ампутація нижньої кінцівки, менеджмент болю, реабілітаційне втручання, функціональне тренування, віртуальна реальність, військовослужбовці.

Introduction. The conditions of the full-scale war in Ukraine have led to a substantial increase in the number of combat-related injuries and traumas, particularly severe limb injuries that frequently result in amputation [1, 2]. At the same time, official statistics on the total number of amputations remain closed to public access. Nevertheless, according to annual data released by the Ministry of Health of Ukraine for January-August 2023, approximately 24,000 amputations were performed during this period. The *Wall Street Journal* reports that nearly 50,000 Ukrainians have lost one or more limbs since the beginning of the war [21]. According to a Protez Hub survey involving 567 respondents, 89,7% had lower limb amputations. Additional research indicates that the ratio of upper to lower limb amputations is approximately 35% to 65%, respectively [25].

Amputation at various limb levels represents a major surgical intervention that significantly affects patients' quality of life, physical condition, mobility, and mental health [3, 7]. In modern medicine, the primary goal is not only to save the patient's life following amputation, but also to ensure conditions for the most complete possible physical and social rehabilitation. A crucial role in this process is played by clinical rehabilitation management, which encompasses comprehensive postoperative care, early initiation of rehabilitation measures, individualised prosthetic fitting, and the provision of psychosocial support to patients [5].

Ensuring high-quality medical care and comprehensive rehabilitation for military personnel and civilians affected by hostilities is a key prerequisite for their return to active life and restoration of functional independence [6, 28].

A substantial proportion of patients after limb amputation face significant physical, psychological, and social challenges. Military amputees, in particular, often strive not

merely for recovery, but for a return to a maximally active and meaningful life. For many of them, this is a matter of identity, dignity, and the continuation of service [4].

One of the most common early postoperative complications is phantom limb pain (PLP), localised in the area of the removed limb. Phantom pain develops in up to 90% of amputees, corresponding to approximately 198,743 patients within the total population of individuals with amputations [19]. International data, including analyses from the United States, indicate that children account for approximately 1,6% of all individuals with amputations; however, these data reflect peacetime conditions. In the context of martial law in Ukraine, the aetiological structure differs substantially, with a significant proportion of injuries resulting from mine explosions and other traumatic mechanisms, which increases the risk of amputation among children. Taking this into account, an expert assumption has been made that children may constitute approximately 5% of the total population of patients with amputations in Ukraine. Accordingly, the proportion of adults (95%) is considered an adjusted estimate that more accurately reflects the target adult population in the Ukrainian wartime context [29].

The relevance of the present study is further supported by the need to develop individualised and effective rehabilitation strategies that enable patients after amputation not only to adapt to bodily changes, but also to live without pain. Scientific evidence suggests that mirror therapy (MT) achieves a clinically meaningful effect in only about 20% of cases of phantom limb pain [23]. Although some studies demonstrate short-term pain reduction with MT, this approach has substantial limitations for a considerable proportion of patients, which reduce its effectiveness or feasibility. Anatomical and technical barriers include high-level amputations, bilateral amputations (absence of a "mirror" limb), as well as contractures or deformities that prevent the creation of a valid visuomotor illusion. Patient-related factors are also important, including low engagement and adherence, as well as reduced motivation due to the monotony of exercises. Under such conditions, virtual reality (VR) is considered a justified second-line approach to sensorimotor rehabilitation. VR reproduces and enhances mechanisms of sensorimotor reintegration, does not require an intact contralateral limb, provides richer sensory feedback, and typically increases patient engagement through gamification and personalisation of scenarios. VR therapy is therefore advisable in cases of ineffective or impractical mirror therapy, in the presence of anatomical limitations (high-level or bilateral amputations), or in situations of low adherence where increased motivation and compliance are required [20, 23].

Thus, investigating the effectiveness of VR therapy for phantom limb pain is highly relevant, as it addresses the urgent need for novel rehabilitation approaches that take into account the specific characteristics of interventions at the pre-prosthetic rehabilitation stage and during preparation for subsequent prosthetic fitting.

The objective of the study is to demonstrate the effectiveness of VR therapy using the VRNOW simulator in the management of phantom limb pain in patients following lower limb amputation.

Materials and Methods. According to current research findings, the aetiology of phantom limb pain (PLP) is complex and multifactorial. Central mechanisms, primarily involving structural and functional changes within the brain, play a leading role in its development; however, peripheral and psychological factors also contribute to symptom formation. Contemporary data support the hypothesis that PLP develops as a consequence of cortical reorganisation following amputation. The loss of sensory input to cortical areas corresponding to the amputated limb allows adjacent regions to occupy this representational space, resulting in abnormal processing of sensory stimuli. Such adaptive neural changes underlie the emergence of the phantom limb pain phenomenon [24].

According to the ICD-10 classification (NC 025:2021), phantom limb pain is coded as G54.6 – *Phantom limb syndrome with pain*. This code is applied to clinical conditions characterised by pain sensations localised in the absent (amputated) limb. The condition is classified within class G00-G99 *Diseases of the nervous system*, category G54 *Nerve root and plexus disorders*. For post-amputation pain, the generally accepted duration criterion of ≥3 months is applied: pain that persists or recurs for more than three months is classified as chronic. Such a clinical course requires a multimodal treatment strategy with an emphasis on sensorimotor interventions and rational pharmacotherapy [17].

Pharmacotherapy for PLP after amputation is largely based on principles used in the treatment of neuropathic pain; however, the volume of condition-specific evidence for this nosology remains limited [10, 12]. Studies evaluating the effectiveness of mirror therapy (MT) demonstrate a substantial reduction in pain intensity, ranging from 64,5% to 68,2%, both in groups performing phantom motor execution and in those engaging in phantom motor imagery [20]. Nevertheless, the quality of evidence varies, and optimal treatment protocols remain undefined [24]. Graded motor imagery includes limb laterality recognition, explicit motor imagery, and mirror therapy, with clinical implementation varying considerably among practitioners. In routine practice, clinicians commonly recommend compression garments, desensitisation techniques, and structured physiotherapy as adjunctive measures [26]. Overall, these findings indicate the absence of unified standardised clinical protocols, with treatment often delivered on an empirical basis and supported by varying levels of evidence. An algorithmic approach typically involves the sequential addition of interventions, progressing from basic to more specialised methods [24].

Given that mirror therapy is a traditional and accessible method for the treatment of PLP in patients after lower limb amputation, it is most commonly applied as the standard non-pharmacological approach during the early stages of rehabilitation. Its widespread use is attributed to ease of implementation, low cost, and the presence of some evidence of clinical effectiveness, largely derived from small randomised and uncontrolled studies [23]. However, based on our clinical observations, MT is currently perceived as a method with substantial limitations. The realism of visual feedback is insufficient, as mirror reflection produces only a partial illusion of limb presence, while the patient remains "anchored" to the real environment, reducing the immersive effect. The configuration of the mirror box is technically inconvenient, and variations in residual limb length complicate positioning, further increasing sensory

incongruence and discomfort. Patient engagement is typically low, with the procedure perceived as monotonous and routine – an issue that is particularly pronounced in military patients experiencing high psychological burden.

According to the clinical pathway of patients with limb amputation, the third stage – *pre-prosthetic rehabilitation* – is specifically designated for the treatment of PLP. At this stage, following complete healing of postoperative scars and reduction of oedema, when the patient transitions to active development of motor functions, VR therapy for PLP may be integrated as an additional non-pharmacological intervention. The entry point for VR intervention corresponds to the moment when the condition of the residual limb permits the initiation of intensive rehabilitation, including targeted treatment of phantom limb pain.

This study constitutes original research. A total of 36 patients after lower limb amputation were enrolled, all of whom were undergoing rehabilitation at the third (*pre-prosthetic rehabilitation*) and fourth (*prosthetic rehabilitation*) stages. The mean age of the male participants was 41,2±8 years. Military personnel constituted 100% of the study sample (n=36), among whom transtibial amputations were performed in 63,9% of patients (n=23), and transfemoral amputations in 36,1% (n=13). Based on these characteristics, inclusion, exclusion, and withdrawal criteria were defined (Table 1).

The study methodology was grounded in the principles of evidence-based medicine and employed validated assessment instruments (scales and questionnaires) alongside parametric statistical methods, specifically the Student's *t*-test for paired samples. This approach enabled a detailed analysis of the dynamics of phantom limb pain (PLP) changes in patients during the rehabilitation intervention. Patient assessment was conducted using the standardised Phantom and Stump Pain Questionnaire (PSPQ), the Short Form Health Survey (SF-36), and a pain diary.

The PSPQ is a specialised tool designed for the multidimensional assessment of patients after amputation and allows differentiation and quantitative evaluation of three distinct types of sensations: phantom limb pain (PLP), phantom limb sensations (PLS), and residual limb pain (RLP). Unlike general pain scales, the PSPQ provides clearer differentiation between phantom pain and phantom sensations, which is critical for selecting an appropriate treatment strategy (e.g. VR therapy versus pharmacotherapy). The PSPQ enables comprehensive evaluation of pain intensity, frequency, and qualitative characteristics, as well as its impact on daily activities and sleep. The questionnaire includes both current and retrospective pain assessment blocks, together with sensory descriptors for the characterisation of painful and non-painful sensations. Within the PSPQ framework, the intensity of PLP and PLS is based on the patient's subjective rating from 0 to 10 on the Numerical Rating Scale (NRS), where 0 indicates no pain; 1-3 mild pain (minimal interference with activities); 4-6 moderate pain (affecting concentration and sleep); and 7-10 severe or very severe pain requiring immediate pharmacological intervention. For the most accurate clinical interpretation, clinicians recommend using the PSPQ in conjunction with a pain diary throughout the rehabilitation course. The diary is completed twice daily (morning and evening) and includes the following components: type of sensation (PLP, PLS, RLP), pain intensity (1-10 points), duration (minutes, hours, constant), pain triggers (weather, stress, touch, prosthesis), and pain relief method (VR therapy, pharmacotherapy) [8, 15, 27].

The SF-36 questionnaire assesses quality of life across eight key domains, divided into physical and psychological components. Each of the eight domains contains questions related to general health, physical functioning, role limitations due to physical health, role limitations due to emotional problems, social functioning, pain intensity, vitality, mental health, social activity, and perceived health status. Scoring in the SF-36 is relatively complex, as each response is assigned a score ranging from 0 to 100, and some items are reverse-coded (e.g. "never" corresponds to 100 points, whereas "always" corresponds to 0 points). Interpretation of results is as follows: 0-40 points indicate a low level (significant limitations), 41-60 points a moderate level (typical for individuals with chronic conditions or age-related changes), and 61-100 points a high level (good quality of life) [11, 22].

Table 1

Inclusion, Exclusion, and Withdrawal Criteria for Patients after Lower Limb Amputation

Inclusion criteria	Exclusion criteria	Withdrawal criteria
Age 35-45 years. Unilateral lower limb amputation at the transtibial or transfemoral level. Presence of persistent phantom sensations and/or pain. Complete healing of the postoperative wound, residual limb formation, preparation for prosthetic fitting (Stage III – pre-prosthetic rehabilitation). Initial or active stage of gait training with a prosthesis (Stage IV – prosthetic rehabilitation). Ability to understand instructions; absence of severe cognitive impairment.	Epilepsy, seizure disorders, or pronounced cybersickness (motion sickness in virtual environments). Severe decompensated cardiovascular diseases, acute infectious diseases, or psychiatric disorders. Presence of unhealed open wounds, pronounced contractures, or inflammatory processes in the residual limb that restrict movement. Severe uncorrected visual impairment or vestibular disorders preventing the use of a VR headset.	Patient refusal to continue participation at any stage without explanation. Occurrence of adverse effects such as severe headache, nausea, or dizziness following VR therapy sessions. Need for repeat surgery (re-amputation) or development of acute intercurrent illnesses. Missing more than 20-30% of scheduled VR therapy sessions.

Statistical data processing was performed using the Statistica 13.0 software package (StatSoftInc., licence No. JPZ8041382130ARCN10-J), with calculation of the following parameters: x – arithmetic mean; S – standard error of the mean; t – significance criterion for normally distributed samples of equal size. Differences were considered statistically significant at $p<0,05$.

The study was conducted in accordance with the principles of bioethics outlined in the Declaration of Helsinki *Ethical Principles for Medical Research Involving Human Subjects* and the *Universal Declaration on Bioethics and Human Rights* (UNESCO). Accordingly, patients after amputation were provided with comprehensive information regarding the nature and scope of the rehabilitation intervention. All participants gave written informed consent to take part in the study; the consent form was reviewed and approved by the Biomedical Ethics Committee of the Medical Centre "Path to Health" LLC (Protocol No. 23, dated 28 October 2024). The study design excluded any possibility of patient identification, thereby ensuring compliance with ethical standards, patient rights, and confidentiality. Rehabilitation was delivered within the framework of the Medical Guarantees Package No. 53, *Medical Rehabilitation for Adults and Children in Inpatient Settings*, approved by the Resolution of the Cabinet of Ministers of Ukraine dated 15 December 2023, No. 1503.

Rehabilitation care was provided on the basis of predefined strategies, principles, goals, and objectives, taking into account the functional status of patients after amputation, their rehabilitation potential, and adherence to established rehabilitation levels and stages. A patient-centred approach to rehabilitation intervention for amputees encompassed the following components: information provision, participation, partnership, collaboration, self-management, and shared goal setting.

The study was conducted at the Medical Centre "Path to Health" LLC and consisted of two 14-day courses during the 2024/2025 period, with the involvement of a multidisciplinary specialist team operating under patient-centred care principles. The study was designed to evaluate the effectiveness of VR therapy using the VRNOW simulator (Declaration of Conformity No. 1 dated 21 October 2024) in patients with phantom limb pain following lower limb amputation. The rehabilitation programme was individualised for each patient based on examination findings in accordance with the International Classification of Functioning, Disability and Health (ICF). Standard rehabilitation measures were implemented in line with clinical guidelines. Daily patient sessions lasted between 20 and 45 minutes, depending on the rehabilitation stage.

Table 2

Software Components and Description of the Rehabilitation Intervention for Patients after Lower Limb Amputation

Intervention stages		Types of virtual interventions		
Stage III – Pre-prosthetic rehabilitation 14 days, 20-30 min twice daily	Stage IV – Prosthetic rehabilitation 14 days, 35-45 min twice daily	Game-based tasks	Dynamic movement and obstacle navigation	Daily-life and cognitive scenarios
Detailed description of interventions				
"Virtual Limb" mode: the patient sees a virtual leg and attempts to perform simple movements; the brain receives a visual signal that the limb "exists" and is "controllable", disrupting the maladaptive phantom pain loop.	**Gait symmetry training:** the patient sees both limbs in VR and aligns step length using visual cues generated by the system, which analyses step length and prosthetic stance time.	**Football:** the patient sees the virtual limb and kicks a ball. At Stage III this trains phantom motor control; at Stage IV it requires weight transfer onto the supporting limb and balance control during the swing phase.	**"Park / Forest":** walking along uneven paths where the system simulates different surfaces, requiring adaptation of step length and reaction speed (especially relevant at Stage IV with a prosthesis).	**"Kitchen" or "Public space":** orientation in confined environments involving turning on the prosthesis, reaching objects on shelves, and manoeuvring between furniture.
Isometric exercises: muscle contraction of the residual limb in a gamified format (e.g., "pressing" a virtual button with the virtual foot).	**Dynamic balance:** tasks requiring centre-of-mass displacement (e.g., avoiding obstacles).	**Basketball:** vertical balance training; reaching for the ball and throwing it into a basket (stimulates centre-of-mass shift).	**Object avoidance:** trunk leaning to avoid virtual objects.	**Object collection:** precision tasks using the "phantom" or prosthetic limb to improve proprioception.
Desensitisation: virtual interaction with objects (pushing a ball, tactile contact).	**Environmental adaptation:** walking on different virtual surfaces.	**Running:** coordinated movements of upper and lower limbs.	**Stepping over objects:** negotiating virtual obstacles.	**Entertainment:** gamified patient engagement.

Figure 1. Application of VR therapy using the VRNOW simulator

The VR therapy methodology using the VRNOW simulator is based on principles of neuroplasticity and the visual substitution approach (Mirror Therapy 2.0). Prior to intervention, baseline assessment of phantom limb pain intensity, residual limb range of motion, and psycho-emotional status was performed. Patients were fitted with a VR headset and a system of motion sensors (trackers). Trackers were attached to the intact limb and to the residual limb (socket interface) to enable accurate spatial motion tracking. The system generated a personalised three-dimensional body model of the patient, in which a virtual limb appeared at the site of amputation (Table 2).

When working with phantom limb pain (PLP), the physical therapist seeks to convince the patient's brain that the limb is intact, relaxed, and under voluntary control. The primary objective is not functional training, but rather the "reprogramming" of neural connections within the cerebral cortex, which enables attenuation of the phantom pain syndrome.

The core feature of VR therapy is the creation of an illusion that the amputated limb is once again present and functioning. A synchronisation process occurs in which the patient moves the residual limb while simultaneously observing, through the VR headset, a fully formed virtual limb performing the corresponding movement. The brain thus receives the visual confirmation of movement that is otherwise absent. This process resolves the conflict between visual input and proprioceptive feedback, which is considered a key mechanism underlying phantom limb pain. The therapist may additionally apply synchronous tactile stimulation to the patient's residual limb at the moment when the patient observes contact with the virtual limb in the VR environment. This further enhances the sense of limb "ownership". VR therapy is preferably conducted in relaxing virtual environments in order to reduce overall stress levels, which are known to exacerbate pain (Figure 1).

The VR system is utilised to stimulate motor recovery, visuospatial orientation, reduction of phantom limb pain, and psycho-emotional adaptation. Under these conditions, a relevant clinical comparator in the form of an alternative second-line non-pharmacological technology is effectively absent. Accordingly, no formal comparator was employed, and VR therapy was considered as an independent therapeutic option targeting a clearly defined patient population with phantom limb pain who demonstrate low motivation for mirror therapy [9, 14, 18, 20, 23].

Results. At the initiation of VR therapy, patients after lower limb amputation reported residual limb pain. According to the Numerical Rating Scale (NRS), pain intensity was moderate in 61,1% of cases (n=22) and mild in 38,9% (n=14). Following completion of the treatment course, complete absence of pain was observed in 33,3% of patients (n=12), indicating a high therapeutic effectiveness of VR therapy. The number of patients with moderate pain decreased almost fourfold (from 22 to 6 individuals). The remaining 50% of patients (n=18) shifted to the "mild pain" category, indicating a transition of the pain syndrome to a controlled, low-intensity form (Table 3).

Analysis of the frequency of pain episodes demonstrated a substantial prolongation of remission periods. Prior to VR therapy, the majority of patients (66,6%, n=24) experienced pain on a daily basis (constantly or several times per day). After the intervention, infrequent pain episodes became the dominant category, observed in 47,2% of patients (n=17), while the number of cases of constant pain decreased by 97,2% (to n=1). The most pronounced positive changes were observed in the "cutting" and "burning" pain descriptors, which decreased three- to fourfold. As these sensations are often associated with a neuropathic pain component, their reduction supports the hypothesis of sensorimotor cortical "reprogramming" mediated by visual feedback in VR. Complaints of "pressing" pain decreased by 53% and "pulsating" pain by 57%, which correlated with reduced pain intensity and decreased muscle tension in the residual limb, likely resulting from immersive relaxation within the virtual environment. These findings support the recommendation to incorporate VR therapy into standard pre-prosthetic preparation protocols, as reduction of local residual limb pain is a critical factor for successful prosthetic training.

As VR therapy acts directly on neural networks within the brain, the dynamics of phantom limb pain (PLP) were generally more pronounced than those observed for residual limb pain (RLP) (Table 4).

Table 3

Residual Limb Pain (RLP) Indicators According to the PSPQ

Descriptors	Indicators	
	Before VR therapy (n=36)	After VR therapy (n=36)
Do you experience pain in the residual limb? (absolute numbers)		
Yes	26	10
No	0	12
Sometimes	10	14
Pain intensity according to the NRS (absolute numbers)		
No pain (0 points)	0	12
Mild pain (1-3 points)	14	18
Moderate pain (4-6 points)	22	6
Severe pain (7-10 points)	0	0
Pain frequency (absolute numbers)		
Constant	8	1
Several times a day	16	5
Several times a week	12	13
Less frequently	0	17
Pain characteristics* (absolute numbers)		
Pulsating	14	6
Cutting	8	2
Pressing	15	7
Burning	6	2

*Note: * The total number under pain-character descriptors may exceed 36, as patients could report more than one type of sensation simultaneously.*

Table 4

Phantom Limb Pain (PLP) Indicators According to the PSPQ

Descriptors	Indicators	
	Before VR therapy (n=36)	After VR therapy (n=36)
Do you experience pain in the absent part of the limb? (absolute numbers)		
Yes	30	8
No	0	16
Sometimes	6	12
Pain intensity according to the NRS (absolute numbers)		
No pain (0 points)	0	16
Mild pain (1-3 points)	12	16
Moderate pain (4-6 points)	24	4
Severe pain (7-10 points)	0	0
Duration of pain episodes (absolute numbers)		
Seconds	10	21
Minutes	18	10
Hours	8	5
Constant	0	0
Pain characteristics* (absolute numbers)		
Shooting	18	8
Burning	15	6
Constricting	12	5
Tearing	9	1

*Note: * The total number under pain-character descriptors exceeds 36, as phantom limb pain is often mixed in nature.*

Table 5

Phantom Limb Sensation (PLS) Indicators According to the PSPQ

Descriptors	Indicators	
	Before VR therapy (n=36)	After VR therapy (n=36)
Nature of sensations* (absolute numbers)		
Tingling / itching	14	18
Warmth / cold	10	12
Sensation of movement (kinaesthesia)	6	24
Sensation of position (static)	22	4
Phantom geometry (absolute numbers)		
Natural length and shape	12	28
"Telescoping" (shortening)	16	6
Distortion of shape	8	2
Do you feel the phantom limb? (absolute numbers)		
Yes (constantly)	28	6
No	0	4
Sometimes (episodically)	8	26
Intensity / clarity of sensations (absolute numbers)		
Weak / barely noticeable	4	22
Moderate	20	10
Pronounced / intrusive	12	0

*Note: * Patients often reported more than one type of sensation simultaneously.*

Table 6

Dynamics of SF-36 Quality of Life Questionnaire Indicators

SF-36 descriptor	Before VR therapy (n=36)	After VR therapy (n=36)	Increase	Significance level
BP (Bodily Pain)	28,4 ± 10,2	56,8 ± 8,4	28,4	≤ 0,001
MH (Mental Health)	32,5 ± 9,6	58,2 ± 7,5	25,7	≤ 0,001
RE (Role-Emotional)	30,2 ± 15,4	54,5 ± 12,1	24,3	≤ 0,01
RP (Role-Physical)	12,0 ± 8,2	30,5 ± 10,3	18,5	≤ 0,05
PF (Physical Functioning)	20,5 ± 7,8	38,0 ± 9,2	17,5	≤ 0,05
VT (Vitality)	35,0 ± 11,3	51,0 ± 9,4	16,0	≤ 0,05
SF (Social Functioning)	38,6 ± 12,5	52,0 ± 10,8	13,4	≤ 0,05
GH (General Health)	41,2 ± 10,1	48,6 ± 8,9	7,4	≥ 0,05
GHI (Global Health Index)	38,0 ± 11,2	50,0 ± 9,0	12,0	≤ 0,01

Following VR therapy, the proportion of patients reporting "no pain" for phantom limb pain (PLP) reached 44,4% (n=16) among individuals after lower limb amputation. This finding supports the concept that VR represents a pathogenetically oriented treatment for phantom phenomena, as it modulates central mechanisms of neuroplasticity by effectively "deceiving" the brain. Concurrently, the number of patients with moderate PLP decreased sixfold (from 24 to 4 individuals), indicating a high sensitivity of cortical centres to visual stimulation. A substantial reduction in pain duration was also observed, with 58,3% (n=21) of patients experiencing pain episodes lasting only seconds. This enabled a marked reduction in analgesic dosage and indicates the capacity of VR therapy to prolong pain-free remission periods and reduce overall nervous system sensitisation. The most pronounced positive dynamics were observed for neuropathic descriptors such as burning, constricting, and tearing pain, with only 22,2% (n=16) of patients reporting shooting pain, which further confirms the effectiveness of VR in suppressing abnormal paroxysmal activity within the sensorimotor cortex.

In contrast to pain, phantom limb sensations (PLS) often did not disappear completely during the study, but rather underwent qualitative transformation, becoming less intrusive, more controllable, or changing in character. Prior to VR therapy, the majority of patients (n=22) described the phantom limb as being "fixed" in a specific, often uncomfortable position (Table 5).

One of the most distinctive outcomes of the VR intervention was a qualitative transformation of PLS, whereby the number of patients experiencing voluntary movement of the phantom limb increased fourfold (from 6 to 24 individuals), indicating restoration of a dynamic neural representation of the limb. VR technologies also helped to overcome the telescoping effect (shortening of the phantom limb) and limb deformation, restoring the sensation of natural limb length in 77,7% (n=28) of patients. Prior to therapy, 12 patients described their sensations as pronounced and intrusive, interfering with concentration; following the

VR course, such complaints disappeared completely, while 61,1% (n = 22) of patients reported sensations that shifted to the category of weak or barely noticeable. An increase in mild tingling (paraesthesias) accompanied by pain reduction is often interpreted as a substitution of pathological pain with neutral sensory noise, which represents a favourable prognostic sign. Importantly, phantom sensations did not merely diminish, but transformed from static and intrusive to dynamic and controllable, thereby restoring the brain's proprioceptive body map, which is fundamental for subsequent prosthetic control.

Analysis of patients' daily pain diaries revealed patterns that are not always evident during single-time PSPQ assessments. Morning recordings were predominantly characterised by complaints of residual limb pain (RLP) and PLS, with RLP often associated with morning oedema and initial contact with the prosthetic socket. Evening recordings demonstrated a peak in PLP, correlating with accumulated fatigue and psycho-emotional exhaustion. Notably, patients reported the greatest effectiveness of VR therapy in the evening as a means of rapid relief from acute pain episodes. Among the main pain triggers identified by patients were: for RLP, prosthesis use and tactile contact in 85% of cases; for PLP, weather conditions and stress in 70% of cases. PLS were most frequently reported at rest, when the brain was not receiving other intense sensory input. According to diary data, 77,7% of patients (n=28) reported that VR therapy completely replaced the use of "rescue" doses of analgesics during evening phantom pain attacks. For RLP, the best outcomes were achieved through a combination of VR therapy and mechanical unloading. As a result of VR training, the average duration of phantom pain episodes decreased from 45-60 minutes to 10-15 minutes. Patients noted in their diaries that following VR sessions the "phantom limb relaxes" and pain transforms into mild tingling. The diary-based monitoring method confirmed that VR therapy is not only a cumulative intervention, but also an effective tool for acute self-management of pain.

Based on baseline SF-36 questionnaire data, the group's Global Health Index (GHI) was 38,0±11,2 points, corresponding to the upper limit of a low quality-of-life level. The primary factors contributing to the reduced overall score were critically low values for Physical Functioning (PF) (20,5±7,8 points) and Role-Physical (RP) (12,0±8,2 points), whereas patients' Mental Health (MH) remained relatively stable, which constitutes a positive indicator for further rehabilitation (Table 6).

Following completion of the rehabilitation intervention, patients demonstrated a positive dynamic in the physical component of quality of life, which was directly associated with the initial successful acquisition of prosthetic use skills. At this stage, patients gradually transitioned from a state of functional limitation to functional capability. In particular, significant improvements were observed in the physical domains (PF and RP): Physical Functioning (PF) increased by 17,5 points ($p \leq 0,05$), indicating the onset of confident prosthetic use at the level of basic skills, while Role-Physical (RP) increased by 18,5 points ($p \leq 0,05$), reflecting partial restoration of the ability to perform everyday activities. These findings provide direct evidence of the effectiveness of VR therapy in domains related to dynamic mobility and activities of daily living, where patients were not merely fitted with a prosthesis but were actively trained to perform routine tasks using it.

Pain management outcomes demonstrated the largest improvement in the Bodily Pain (BP) domain, with an increase of 28,4 points, indicating effective relief of phantom limb pain and residual limb discomfort ($p \leq 0,001$). The Mental Health (MH) score increased by 25,7 points ($p \leq 0,001$), suggesting attenuation of depressive tendencies and the formation of a positive psychological orientation towards recovery. This indicates a stabilisation of the overall mental state of the group, with a marked reduction in depressive episodes. The combined reduction in pain intensity and improvement in mental health created a foundation for the successful acquisition of more complex prosthetic gait skills, which is reflected in the observed increases in physical functioning scores.

A substantial improvement was also observed in Role-Emotional (RE) functioning, which increased by 24,3 points ($p \leq 0,01$), confirming that stabilisation of the psycho-emotional state enabled patients to return to productive activity. Correction of the depressive background showed a direct correlation with successful mastery of prosthetic use.

The incorporation of VR methods into the rehabilitation intervention structure resulted in a statistically significant increase in the Global Health Index (GHI) by 12,0 points (from 38,0 to 50,0 points; $p \leq 0,01$), indicating a transition from a low to a moderate level of overall functioning. This increase of 12,0 points is clinically meaningful and suggests that patients moved from a stage of "passive treatment" to one of "active functional adaptation." Visualisation of the absent limb in virtual space generates strong visual afferentation that counteracts pathological sensory convergence within the cerebral cortex, thereby disrupting the maladaptive "pain-expectation-pain" cycle. The reduction in pain following intervention indicates a stable analgesic effect in the majority of patients. Furthermore, VR therapy provides an immersive experience that allows patients to psychologically distance themselves from the traumatic experience of amputation. Engagement in gamified virtual tasks activates the dopaminergic reward system, which is critically important for overcoming apathy and anhedonia.

Discussion. The results of the present study indicate the promising potential of VR therapy using the VRNOW simulator in the management of phantom limb pain in patients after lower limb amputation. The findings support the hypothesis that VR-based intervention may be considered a justified second-line non-pharmacological treatment option for patients with insufficient response to standard therapy. This approach is aimed at modifying sensorimotor mechanisms of pain and combines targeted reduction of phantom limb pain with training of motor control and preparation of the residual limb for functional loading. Thus, VR therapy does not replace conventional treatment modalities, but rather sequentially complements them, offering a rational next step in cases where first-line interventions prove inadequate. Such an approach allows a reduction in the need for escalation of pharmacotherapy, including opioid analgesics, and provides a structured, protocol-based second-line option specifically for patients with the highest clinical need.

Considering the clinical care pathway for patients after lower limb amputation, VR therapy is most appropriately

integrated at the pre-prosthetic rehabilitation stage, following complete scar healing and stabilisation of the residual limb, in cases where phantom limb pain persists and is insufficiently controlled by standard approaches. At this stage, pain reduction, restoration of motor control, and adaptation to functional loading are critical prerequisites for subsequent prosthetic fitting. Importantly, the introduction of VR therapy does not alter the fundamental structure of the rehabilitation pathway, but rather adds a novel therapeutic tool within an already established clinical stage, thereby reducing organisational barriers and facilitating practical implementation in contemporary healthcare settings. In particular, the positive dynamics observed in PSPQ scores and SF-36 outcomes indicate a reduction in manifestations of all three types of sensations (PLP, PLS, and RLP) alongside an overall improvement in quality of life among patients after lower limb amputation.

Notably, the results obtained are consistent with previous studies demonstrating beneficial effects of VR therapy in patients after lower limb amputation (E. Ambron et al., 2021; A. S. Eldaly et al., 2022; E. Keesom et al., 2025) [9, 14, 18].

However, the available international literature is largely limited to isolated case series, small cohort observations, and pilot studies, frequently characterised by heterogeneous intervention protocols, varying pain assessment scales, and divergent inclusion criteria. Well-designed, prolonged courses of VR therapy specifically targeting phantom limb pain of the lower extremities remain scarce, and existing studies do not provide a high level of evidence regarding comparative effectiveness or long-term outcomes within clearly defined clinical subgroups. A distinctive feature of the present study is its focus on the third (pre-prosthetic rehabilitation) and fourth (prosthetic rehabilitation) stages following amputation, where experience with VR therapy using the VRNOW simulator remains limited [13, 16].

In the Ukrainian context, the integration of VR into the rehabilitation process is particularly relevant, as the challenge is compounded by the rapid increase in the number of patients with amputations during martial law, a substantial proportion of whom suffer from phantom limb pain. The development of chronic pain syndromes in this population has not only clinical but also pronounced social and economic consequences: persistent pain limits rehabilitation potential, complicates return to daily activities, reduces opportunities for professional reintegration, and increases demand for medical and social resources.

Conclusions. The proposed VR therapy using the VRNOW simulator for patients after lower limb amputation demonstrates a targeted effect in reducing residual limb pain, phantom limb pain, and phantom limb sensations through staged sensorimotor stimulation and restoration of neural connections. During Stage III (pre-prosthetic rehabilitation), the use of the *Virtual Limb* mode, isometric exercises, and virtual interaction with objects facilitates the formation of controlled visuomotor feedback. This contributes to disruption of the pathological phantom pain cycle, reduction of residual limb hypersensitivity through desensitisation, and gradual integration of the “virtual limb” into the patient’s body schema. As a result, the intensity of phantom sensations decreases and perception of the missing limb becomes normalised.

During Stage IV (prosthetic rehabilitation), the therapeutic focus shifts towards restoration of proprioception, gait symmetry, and dynamic balance. Virtual scenarios involving adaptation to different surfaces, obstacles, and spatial tasks activate sensorimotor integration mechanisms, promote more precise prosthetic control, and reduce pain manifestations associated with residual limb overload. Training of weight transfer, centre-of-mass displacement, and movement accuracy enhances deep sensory perception and restores adequate proprioceptive feedback.

Final outcomes for residual limb pain assessed using the PSPQ within the NRS framework demonstrated a reduction in the number of patients with moderate pain from 22 to 6, while 33,3% of respondents (n = 12) reported complete absence of pain, with a mean score of 1,83±0,28 points ($p \leq 0{,}001$). A significant reduction was observed in the number of patients with persistent phantom limb pain, from 30 to 8 individuals, while in 44,4% of respondents (n=16) pain resolved completely, with a mean score of 1,44±0,28 points ($p \leq 0{,}001$). Short-term pain episodes predominated over prolonged ones, and the frequency of neuropathic pain characteristics decreased substantially. A pronounced reduction in persistent phantom sensations was also observed, from 28 to 6 patients, with complete resolution of intrusive manifestations. The proportion of episodic and weak sensations increased. Normalisation of the phantom limb representation was achieved: the number of cases with a natural limb shape increased from 12 to 28, while manifestations of telescoping and distortion decreased markedly, indicating improved sensorimotor integration.

The study results demonstrated statistically significant improvements across most SF-36 domains. The greatest increase was observed in the Bodily Pain domain (BP +28,4 points; $p \leq 0{,}001$), confirming a pronounced analgesic effect. Substantial improvements were also noted in Mental Health (MH +25,7 points; $p \leq 0{,}001$) and Role-Emotional functioning (RE +24,3 points; $p \leq 0{,}01$), indicating stabilisation of the emotional state.

Positive dynamics in physical domains (PF +17,5 points; RP +18,5 points; $p \leq 0{,}05$) confirm successful prosthetic mastery and increased independence in activities of daily living. The Global Health Index (GHI) increased by 12,0 points ($p \leq 0{,}01$), reflecting a clinically meaningful transition to a higher level of functioning and further confirming the effectiveness of VR therapy.

Thus, the incorporation of VR technologies into a structured rehabilitation programme constitutes an effective tool for reducing residual limb pain, correcting phantom limb pain and phantom sensations, and restoring proprioception, which collectively enhances functional capacity and quality of life in patients after lower limb amputation.

Conflict of Interest. The authors declare no conflict of interest.

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