The Efficiency of Virtual Reality Based Physiotherapy on Upper Extremity Mobility in Stroke Patients

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ABSTRACT

Background: The importance of robotics and virtual reality has recently grown and complemented traditional physiotherapeutic approaches. These novel techniques facilitate the training of weakened movements and are customized to meet patient needs.

Aim: To evaluate the effects of virtual reality based therapy using a physiotherapy device in stroke patients and compare it to conventional therapy.

Methods: We recruited 16 post-stroke patients for our study and divided them into 2 groups – the experimental (using virtual reality) and control group (using conventional therapy). We conducted 10 sessions of upper extremity therapy, each 30 minutes long. The differences in the measured parameters were subsequently evaluated using standard clinical tests, dynamometry, and the device-based tests. The Wilcoxon signed-rank test and the Mann-Whitney U test were used to evaluate the data. The significance level was set at 0.05.

Results: We found significant improvement in 6 of the 6 parameters in the experimental group and another significant improvement in 2 of the 6 parameters in the control group. Statistical comparison of the effects of the two interventions showed only one parameter to undergo a significant change.

Conclusion: The findings of our study indicate that virtual reality based therapy is more effective compared with conventional therapy, as it improves the specific skills and functions of the upper extremity. There were, however, no statistically significant differences between the two therapies.

KEY WORDS

stroke; hemiparesis; upper extremity; cognitive rehabilitation; virtual reality; robotic therapy; physiotherapy

INTRODUCTION

The human brain controls all the bodily activities, namely body movement, sense organs, thought processes, and emotions. All the parts of the brain are interconnected and in continuous interaction. Stroke frequently causes damage to areas associated with motor and cognitive function. In the case of the most common cerebral artery stroke, middle cerebral artery (MCA) syndrome, the most damaged region is the hand and its motor function. The prevalent impairment is to movement and sensation (1). A number of patients with MCA stroke report a good recovery of their postural functions and locomotion, but the upper extremity (hand) function is the last to be restored. Cortical control of the hand is one of the most impaired brain regions. The body schema may also be subsequently impaired, with elements of hemispatial neglect and learned non-use (2). Upper extremity (UL) impairment after stroke is caused by muscle weakness, loss of motor control, spasticity, and abnormal synergies, which are probably related to the increasing use of subcortical regions. Both local muscle coordination and coordination between upper extremity segments is impaired (3). Studies also suggest that only 5–20% stroke patients recover the original function of the upper extremity, and only 6% patients are satisfied with the function of the affected upper extremity (1).

In addition to motor disorders, there are also cognitive changes including deficits in attention, orientation, memory, thinking, apraxia, agnosia, aphasia,
and abstraction. Školoudík et al. (4) reports that up to 92% of acute stroke patients have a cognitive deficit. These patients have a poorer prognosis and greater difficulties with the activities of daily living (ADL) (5). The cognitive deficit may be reversible, however, and the majority of patients recover within 3 months post stroke. Factors determining the emergence of a cognitive deficit primarily include age, presence of an infection, stress, speech disorder, and the location of the lesion (6). Not all the manifestations necessarily present together, the patients may only register some of the changes and in varying quality (7).

Lost functions spontaneously recover to a certain degree after stroke. The condition improves in the first few hours as the oedema recedes and the function of neurons outside the necrotic area is restored. The condition improves over the course of a few days or months as a result of the settlement of synapses vacated after the death of the eliminated brain neural axons and due to the activation of reserve functional junctions. Movement recovery may take several months; Votava (8) reports that the final results are achieved between 6 months and 5 years after the attack.

In addition to progress in diagnosis, given particularly by the use of new imaging methods, timely and effective treatment and rehabilitation have also advanced considerably. Rehabilitation (RHB) aims at encouraging the restoration of the cerebral functions and prevention of secondary changes. The success of treatment depends on the damage to the central nervous system (CNS), on overall fitness, family background, motivation, the patient’s age and co-morbidity. It is also influenced by the timeliness and intensity of therapy, targeted tasks, and multisensory stimulation of the patient. The first 6 months after stroke in particular are crucial in terms of the CNS restoration, and therefore rehabilitation has the greatest impact in this period. Individual therapies should be purpose-oriented, combine with daily and work activities through form and content, and include multisensory stimulation (1). Repetitive training of motor and cognitive functions affects nerve cells, increases the amount of dendrites, forms new neural connections, and promotes the development of an important quality of the nervous system – neuroplasticity (9). It is the ability of the nervous system to change depending on internal or external conditions, both physiological (load, system inactivity) and pathological (damage), or on experience and repetitive stimuli (learning). Certain parts of the brain may then take over functions that had been destroyed in other impaired areas. Brain plasticity is one of the most significant mechanisms promoting stroke recovery (6).

**Virtual reality rehabilitation**
Established therapeutic procedures have in recent years been complemented with new techniques based on robotic and virtual therapy, designed chiefly to improve proprioception and motor skills (10). These techniques are successful in involving and motivating patients in therapy, which makes adequate and purposeful use of game elements and various activities of daily living (2, 5). Virtual reality (VR) therapy is a process of re-learning motor and cognitive skills modified as a result of stroke-induced brain damage. VR therapy aids intense training through an easy and frequent repetition of complex functional movements and simultaneous incorporation of various stimuli in the therapy (11). This activates residual motor functions and improves the range of motion and muscle strength. The goal is to achieve functional changes by strengthening, consolidating or confirming previously learned patterns of behaviour, or by creating new patterns of activities, and thus improving the ability to cope with everyday routine situations. Adequate therapy restores both motor and cognitive functions, which are vital for the proper functioning of the sensorimotor system. It simultaneously targets multiple cognitive functions that are interconnected and interacting (12). For example, memory is associated with focused attention and executive functions. Multitasking, such as driving while communicating with the passenger, is common in daily life. These parallel activities influence one another and result either in improved performance (higher quality of the activity) or inferior performance (activity slowdown). Cognitive-motor interference is significant for ADL and deteriorates in stroke patients.

Other advantages of virtual reality therapy include the customization of therapy, a range of degrees of difficulty, objective measurements of therapeutic progress and results, and feedback. Specific programmes then serve to collect, quantify, analyse, and store the data. VRT also allows for analysing the performance from various perspectives and provides the user with real-time feedback (13). In addition to the option of triggering external stimulation – such as the illusion of a real environment with different sensory information – it is assumed that this purpose-oriented and specific training triggers plastic changes of the CNS in response to internal stimulation of higher cortical centres. This interactive cognitive training in virtual environment is based on the idea that the stimulation of brain areas involved in motor function activates downstream cortical areas responsible for the execution of movement. A key role here is played by “mirror neurons”, which are
activated during both action execution and motor imagery (14).

VR therapy has both advantages and disadvantages. The disadvantage of virtual reality is the absence of a “normal” tactile feedback, which is fundamental in terms of sensorimotor learning principles. In addition, computer-assisted movement can be viewed as a mere imitation of real movement, which may cause inaccuracies both in the actual execution of the movement and in its planning. Too high a level of computer assistance may, paradoxically, lead to a lower participation of patients in therapy, and may not motivate them to conduct the necessary muscular activity. Virtual experience and interaction may also cause motion sickness with symptoms of disorientation, postural uncertainty, sweating, eye pain, nausea etc. Patients may also have difficulty distinguishing between a virtual world and reality. There are also cases described where virtual reality causes anxiety (15).

Device
The instrument under research is a therapeutic and diagnostic device designed for patients with reduced or impaired upper extremity function. The main goal of therapy is to recover and improve the upper extremity motor function, namely to re-learn the existing and new motion patterns and improve coordination. Other goals include the prevention of secondary changes (spasticity, contractions) and decreased risk of muscle strength loss.

The device is a mechanical arm exoskeleton, designed to hold the weakened (paretic) extremity of patients with reduced mobility. The mechanical springs of the exoskeleton support the extremity in the gravitational field and assist with targeted movement during exercises. The movement of the paretic extremity appears optimal, almost within the physiological range, in the virtual environment. Functional exercise software is developed so that the exercise can be tailored to the patient’s capacities as the basis for optimal motivation.

Therapy includes simple one-dimensional and complicated three-dimensional exercises targeting object reaching and grasping and other functions and qualities of the movements of the upper extremity, based on the patient’s current need and therapy goals. All the functional exercises are tailored to the patient’s condition in a calibrated working environment. The exoskeleton therapy also requires the involvement of cognitive function in the exercise, such as visual perception – object recognition and orientation in space, attention, problem understanding and solving.

The evaluation software consists of a special group of specific exercises designed to analyze the patient’s skills. All relevant angles of the joints and arm positions are recorded during the assessment exercises, and the data serves for the analysis of movement quality and coordination.

Figure 1  Upper extremity virtual rehabilitation of a stroke survivor
OBJECTIVE

The aim of the experiment was to evaluate the therapeutic effects of the virtual reality-based device in stroke patients with a motor or sensory upper extremity deficiency, and to compare the results of virtual reality therapy with the results of standard therapy in stroke patients.

METHODS

Subjects

The population were 16 survivors of a middle cerebral artery stroke, 12 males and 4 females. 11 subjects were with a right middle cerebral artery stroke (clinically manifested left-sided hemiparesis) and 5 subjects with a left middle cerebral artery stroke (right-sided hemiparesis). The affected extremity was dominant in 7 subjects and non-dominant in 9 subjects. The population included patients with spasticity up to score 3 of Modified Ashworth scale. All the subjects were randomized into two groups, the experimental group (Table 1) and the control group (Table 2). The average age of subjects in the experimental group was 65.13 (± 7.02) years, with the mean time since stroke at 25 (± 7.416) days. The average age of subjects in the control group was 63 (± 8.85) years, with the mean time since stroke at 27.37 (± 6.56) days. The subjects had no other neurological deficit, no infectious disease, febrile state or severe cognitive deficit which would prevent collaboration during the testing period and the experiment. All the subjects had been informed about the course of the measurements and signed a written consent to participate in the study. The study was approved by the Ethics Committee of the Faculty of Health Sciences of Palacký University in Olomouc, under the number UPOL-6450/1040-2015 dated 22 January 2015.

Table 1 Subjects in the experimental group

<table>
<thead>
<tr>
<th>Experimental group</th>
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<tbody>
<tr>
<td>Patient</td>
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<tr>
<td>Subject 1</td>
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<td>Subject 2</td>
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<tr>
<td>Subject 3</td>
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<td>Subject 4</td>
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<td>Subject 5</td>
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<tr>
<td>Subject 6</td>
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<tr>
<td>Subject 7</td>
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<tr>
<td>Subject 8</td>
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</table>

Legend: UP – upper extremity

Table 2 Control group

<table>
<thead>
<tr>
<th>Control group</th>
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<tbody>
<tr>
<td>Patient</td>
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</tr>
<tr>
<td>Subject 1</td>
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<tr>
<td>Subject 2</td>
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<td>Subject 3</td>
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<td>Subject 4</td>
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<td>Subject 5</td>
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<td>Subject 6</td>
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<tr>
<td>Subject 7</td>
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<tr>
<td>Subject 8</td>
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</tbody>
</table>

Legend: UE – upper extremity

Measurements

The subjects were randomized into two groups in the study – the experimental and the control group. The therapy was conducted for the duration of two weeks (10 sessions, 30mins). Subjects in the experimental group underwent virtual reality therapy using the tested device, while subjects in the control group underwent manual physiotherapy designed to restore the upper extremity function. As the subjects had been randomly recruited from the Olomouc Teaching Hospital, Rehabilitation Unit, they remained part of the therapy programme of the Unit throughout the experiment.
At the beginning and at the end of the experiment, the subjects were tested using standardized clinical tests (motor function: Action Research Arm Test, Fugl-Meyer Motor Assessment; cognitive function: Mini-Mental State Examination), dynamometry, and instrumental tests ("Vertical Catch" and "Reaction Time"), and the results were duly recorded. The clinical tests were selected based on their validity and reliability for the diagnosis (16). The motor, sensory, and cognitive functions and the grip strength of the subjects were tested. These tests were used to assess differences in measured parameters at the beginning and at the end of the experiment between the subject groups. The tests were held at the same time of day, in the same room, and with the same therapist in order to minimize inaccuracies and errors.

The subjects were seated during the dynamometry test. The shoulder, forearm, and wrist were in a neutral position, with the elbow flexed at 90 degrees. The subjects grasped the dynamometer with their affected hand and were asked to perform a maximal contraction. The grip was measured three times in a row and the mean of these values was recorded. The resulting value was measured in kilograms (kg).

The robot-based assessment was conducted in special programmes of the tested device. It is a group of assessment exercises serving to evaluate the abilities of the subject. During the assessment exercises, all relevant angles of the joints and arm positions are read at the 100 Hz sampling frequency and saved. Based on the generated data, the quality of movement and the type of coordination are analysed. The device evaluates two main parameters, the Hand Path Ratio (HPR) and the Reaction Time (RT). HPR serves to evaluate movement quality. The value is the ratio of the patient's hand trajectory and the straight-line distance between two targets. The value shows the extent to which the patient deviates from the ideal path. A perfect linear movement has a HPR of 1, while HPR 2 indicates that the path of the patient's hand was twice as long as the shortest distance between the objects. The RT parameter is measured in the Reaction Time test, where the software measures the time between the moment the relevant object appears, to which the subject needs to respond, and the moment of the subject's motor reaction. It also evaluates the time between the moment of the object disappearance and the moment of the subject's return to the original position.

Data analysis
The parameter results were first transferred to Microsoft Excel 2016 and basic descriptive statistics of the tested groups added. The data were subsequently evaluated and statistically processed using the software Statistica CZ, version 12. The Wilcoxon Signed-Rank Test was used to determine the effects of virtual reality therapy in the experimental group and of therapy in the control group. The statistical significance level for each group was p ≤ 0.05. The two therapies were also compared with the Mann-Whitney U test. The statistical significance level was also p ≤ 0.05. The findings were presented in quartile box plots.

FINDINGS
Table 3 shows the results of statistical significance for the parameters under study in the experimental and control group. The investigation focused on the effects of the virtual reality therapy in the experimental group, namely on the difference of the parameter results in the input and output measurements, and on the effects of conventional therapy in the control group.

The virtual reality therapy, namely subjects in the experimental group, showed significant improvement in 6 of the 6 parameters monitored. The control group therapy scored significant improvement in 2 of the 6 parameters monitored, while 3 other parameters (ARAT, FMA-UE, and Grip Strength) were close to the statistical significance level with p = 0.068. The Hand Path Ratio (HPR) did not record any improvement in the control group of subjects.

Table 3 Statistical significance for each parameter in the experimental and control group

<table>
<thead>
<tr>
<th>Experimental group</th>
<th>p-value</th>
<th>Control group</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARAT (before and after thp.)</td>
<td>0.018*</td>
<td>ARAT (before and after thp.)</td>
<td>0.068</td>
</tr>
<tr>
<td>FMA - UE (before and after thp.)</td>
<td>0.018*</td>
<td>FMA - UE (before and after thp.)</td>
<td>0.012*</td>
</tr>
<tr>
<td>Grip strength (before and after thp.)</td>
<td>0.018*</td>
<td>Grip strength (before and after thp.)</td>
<td>0.068</td>
</tr>
<tr>
<td>RT (before and after thp.)</td>
<td>0.012*</td>
<td>RT (before and after thp.)</td>
<td>0.012*</td>
</tr>
<tr>
<td>HPR (before and after thp.)</td>
<td>0.012*</td>
<td>HPR (before and after thp.)</td>
<td>0.779</td>
</tr>
<tr>
<td>MMSE (before and after thp.)</td>
<td>0.028*</td>
<td>MMSE (before and after thp.)</td>
<td>0.068</td>
</tr>
</tbody>
</table>

Legend: ARAT – Action Research Arm Test, FMA-UE – Fugl-Meyer Motor Assessment for Upper Extremity, RT – Reaction Time, HPR – Hand Path Ratio, MMSE – Mini Mental State Examination, * refers to statistically significant comparisons at p ≤ 0.05
The aim of the study, however, was to identify and evaluate the therapeutic effects of the device (in the experimental group) and to compare the results with standard therapy in stroke patients. Changes in group parameters were compared between the two groups. The results are specified in Table 4.

The comparison of the parameters for each group of subjects showed a significant change only in the Hand Path Ratio (HPR). Grip Strength was close to the statistical significance level with $p = 0.074$, while the scores of the other parameters varied.

The quartile box plots (Plot 1 to 6) show the distribution of the effects of the experimental and control therapy for each monitored parameter. Table 4 summarizes their $p$ values.

Table 4  Statistical significance for each parameter between the groups

<table>
<thead>
<tr>
<th>Therapeutic effect</th>
<th>$p$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARAT</td>
<td>0.115</td>
</tr>
<tr>
<td>FMA - UE</td>
<td>0.916</td>
</tr>
<tr>
<td>Grip strength</td>
<td>0.074</td>
</tr>
<tr>
<td>RT</td>
<td>0.637</td>
</tr>
<tr>
<td>HPR</td>
<td>0.031*</td>
</tr>
<tr>
<td>MMSE</td>
<td>0.318</td>
</tr>
</tbody>
</table>

Legend: ARAT – Action Research Arm Test, FMA-UE – Fugl-Meyer Motor Assessment for Upper Extremity, RT – Reaction Time, HPR – Hand Path Ratio, MMSE – Mini Mental State Examination, * refers to statistically significant comparisons at $p \leq 0.05$

**DISCUSSION**

A stroke causes a wide range of functional disorders. These include motor as well as cognitive and sensorimotor impairments. Functional recovery after stroke is attributed to neuroplasticity, which is stimulated by high-quality patient care and a carefully selected intensive individual therapy (17). Recent years have seen a natural expansion and integration of new therapeutic devices into physiotherapy. There is therefore a need to constantly test their effects and practical use. Virtual reality finds use, for example, in a broad group of stroke patients, where emphasis is on the motor control exercise using external cues.

Comparing the effects of the therapies under investigation, we found more significant changes in parameters in the experimental group of the subjects compared with the control group of the subjects, using both clinical tests and device-based parameters, the hand grip and the cognitive test (Table 3). This observation suggests that compared with the control group, subjects undergoing virtual therapy have better results in a variety of upper extremity skills and functions according to the selected tests. We found these subjects to have faster reactions, more coordinated and dexterous movements, and a stronger hand grip. The results of this experiment comply with the findings of Feys and Gijbels et al. (18, 19), who also highlight significant improvements in upper extremity motor skills in patients with initial poor motor function of the extremity, where the recovery potential is naturally the highest. They also point at the subjective perception of improved UL movement of the subjects, specifically concerning ADL. The results of the FMA-UE test, considered by many authors to be the most widespread tool to test the voluntary movement, grip, coordination, and reflex activity of the post stroke paretic arm (16), however, yielded almost identical significant results in both the experimental and control group. A positive finding is that therapy using the device under study, which does not support sensitive functions (20), is comparable to high-quality standard manual physiotherapy. The mobility of the paretic extremities of the subjects was also assessed using the device-based instrumental tests. The HPR parameter is focused on the patient ability to reach an object in a defined virtual environment and at a specified time. It evaluates the trajectory of the upper extremity, which should “ideally” be linear. This test provides data primarily about the coordination and accuracy of the movement. The comparison of the effects of the therapies indicated significant changes in the experimental group of subjects. This could be explained by the fact that the arm is lifted in the exoskeleton at a certain position, so that during training the subjects are able to focus more on the execution and targeting of the movement than on holding the upper extremity up against gravity, which enhances coordination and smooth practising of the movement. Another benefit is the immediate feedback determining the success of reaching an object. The results of our research are consistent with, for example, studies by Gijbels and Zimmerli (19, 21). These confirm that the use of virtual reality has a significant impact on movement speed and accuracy in reaching tasks. Johansson (22) also reports in his study that virtual therapy improves attention, accuracy, speed, and timing of movement. Furthermore, studies by Bartolo, Jarrassé, and Gijbels (1, 3, 19) have found that the exoskeleton-based anti-gravity support increases the range of movement, improves movement linearity, coordination, reduces pathological associate movements, and positively affects the quality of ADL. This corresponds to our results. It is also reported that virtual reality based robotic therapy for the upper extremity in chronic stroke patients increases the sensorimotor cortex activity in
Box plot 1 Difference in Action Research Arm Test

Box plot 2 Difference in Fugl-Meyer Motor Assessment for Upper Extremity

Box plot 3 Difference in Grip Strength

Box plot 4 Difference in Reaction Time

Box plot 5 Difference in Hand Path Ratio

Box plot 6 Difference in Mini Mental State Examination
trained functions and the reorganization of the relevant motor maps (23). Another instrumental parameter RT records the time data of the object screening and the time data of the paretic arm reach start time. Comparison of the differences between the interventions again showed identical significant results in both the experimental and control group.

The most widespread and simple test MMSE (16) was selected for the assessment of cognitive functions that enable the processing of and reaction to stimuli and are therefore vital for the sensorimotor system. The results showed improvement in the cognitive function of the experimental group of subjects. We believe the reason is the active participation and interaction with the environment of the patient and the immediate feedback that virtual reality provides. The therapy optimally connects cognitive function with upper extremity mobility by means of dual task training. Švingalová (24) concludes that cognitive function is also linked to education. Cognitive improvement can thus depend on pre-stroke intelligence and education achieved, which were not considered in our research, on attention, imagination, and the ability to learn. McEwen et al. (25) have summarized information from a number of studies confirming that improvement in cognitive function help patients better understand the therapy and develop a quality plan and idea of how to execute the activity. Cognitive training is recommended as a targeted and conscious process that facilitates acquisition of the required skill. Subsequent statistical comparison of both the groups did not reveal a statistically significant difference. The only significant change identified concerned the instrumental parameter HPR (Table 4). This result requires caution, as patients undergoing day-to-day instrumental therapy could have scored higher at the final test (HPR parameter) due to their familiarity with the device. It should also be noted that both the experiment and control form of therapy were conducted as the complement of rehabilitation running in parallel to daily intensive physiotherapy at the inpatient rehabilitation unit of the Olomouc Teaching Hospital. Although the experimental and control groups of subjects underwent the same form and intensity of basic therapy outside our study, it is impossible to accurately assess to what extent the results have been influenced by comprehensive rehabilitation care. We can only agree with conclusions of the above-mentioned authors and confirm that the desired results are due to the synergistic effects of the combination of both – standard physiotherapy and virtual reality therapy, which were observed in the experimental group. A limiting factor of the study could be the small sample of subjects participating in the tests, where it is difficult to establish statistically significant results. The overall results are then affected by patient outliers. It would be beneficial to include one or two more control measures after a time interval, for example one or three months after the therapy in order to objectivise the long-term results of the therapy.

CONCLUSION

Robotic devices continue to develop and improve and their therapeutic effects need to be studied and verified by specific research. The results of our study suggest that virtual reality based therapy is an appropriate tool and complement to standard physiotherapy, has its inherent potential, and could become much more affordable for stroke survivors in the future. The resulting synergistic effects of virtual therapy and standard therapy allow patients to achieve better results, specifically where jointly focused on motor and cognitive functions. This facilitates faster recovery and a higher-quality return to normal life, which is the main goal of rehabilitation.

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