e-ISSN: 0975-9506, p-ISSN: 2961-6093

Available online on www.ijpqa.com doi: 10.25258/ijpqa.16.11.88

International Journal of Pharmaceutical Quality Assurance 2025; 16(11); 563-570

Original Research Article

Impact of Virtual Reality-Integrated Physiotherapy on Upper Limb Performance in Individuals with Stroke: A Controlled Trial

Rajeev Ranjan Sinha[1], Pramod Kumar[2], Ratnesh Kumar[3], Anjani Kumar[4], Sanyal Kumar[5]

[1]Senior Resident, Department of PMR, Nalanda Medical College and Hospital, Patna, Bihar, India.
[2]Assistant Professor, Department of PMR, Nalanda Medical College and Hospital, Patna, Bihar, India.
[3]Assistant Professor, Department of PMR, Patna Medical College and Hospital, Patna Bihar, India
[4]Assistant Professor, Department of PMR, All India Institute of Medical Science, Patna, Bihar, India
[5]Assistant Professor, Department of PMR, All India Institute of Medical Science, Patna, Bihar, India

Received: 10-09-2025 / Revised: 24-10-2025 / Accepted: 27-11-2025
Corresponding Author: Dr. Anjani Kumar
Conflict of interest: Nil

Abstract:

Background: Upper limb impairment is a common and disabling consequence of stroke, limiting independence and quality of life. Virtual reality (VR) has emerged as a novel rehabilitation approach that may enhance motor recovery through task-oriented, repetitive, and engaging practice.

Aim: To evaluate the effectiveness of VR-integrated physiotherapy on upper limb performance in individuals with chronic stroke compared with conventional physiotherapy.

Methodology: A two-armed controlled trial was conducted on 30 individuals with chronic stroke (≥6 months), randomly allocated to an experimental group (VR-integrated physiotherapy) or a control group (conventional physiotherapy). Both groups received supervised therapy three times per week for 12 weeks. Upper limb performance was assessed pre- and post-intervention using the Action Research Arm Test (ARAT), Wolf Motor Function Test (WMFT), WMFT-Time, and Hand Grip Strength (HGS).

Results: Both groups showed significant improvements in all outcome measures ($p < 0.05$). However, the experimental group demonstrated significantly greater gains in ARAT and WMFT scores, faster WMFT-Time, and higher hand grip strength compared with the control group ($p \leq 0.002$).

Conclusion: VR-integrated physiotherapy is more effective than conventional physiotherapy alone in improving upper limb function, motor performance, and strength in individuals with chronic stroke.

Keywords: Stroke rehabilitation; Virtual reality; Upper limb function; Physiotherapy; Motor recovery.

Introduction

Stroke is an acute neurological event resulting from an interruption of blood supply to the brain, leading to variable neurological damages, long-term disability, and mortality [1,2],,. Stroke is regarded as the second or third leading cause of death worldwide and continues to be one of the major causes of acquired disability among adults [3]. Survivors from stroke continue to have persistent functional impairments that significantly reduce independence and quality of life, thus imposing a high burden on individuals, families, and healthcare systems throughout the world.

In the SA, stroke is a major emerging public health concern. Annual incidences of stroke among adults are reported to be around 30–40 per 100,000 population [4]. Almost 20,000 new stroke cases are estimated to occur every year, leading to about 8,000 cases of long-term disability and approximately 4,000 deaths annually [5]. Moreover, the incidence of stroke in Saudi Arabia will likely continue to rise with increasing life expectancy and growing prevalence of risk factors like diabetes, hypertension, and sedentary lifestyle, which makes stroke rehabilitation an urgent healthcare need.

Stroke is associated with impairments across a wide range of physical, sensory, and functional abilities. The typical post-stroke impairments include muscle weakness, fatigue, abnormal muscle tone, sensory loss, cardiovascular deconditioning, impaired coordination, poor balance, and difficulty in walking [6]. These often lead to restriction in the ability of individuals to accomplish functional tasks and full participation in daily life. Among these deficits, impairments of the upper limb are particularly disabling and frequently persist long after the acute phase of stroke.

Upper limb impairments are often more pronounced and functionally limiting compared to lower limb impairments in stroke survivors. Reduced strength, slow and uncoordinated movements of the affected arm and hand, and limited functional use during daily activities are common. Reach movements are often problematic because of disturbed timing, altered coordination, and abnormal postural adjustments. Impairments in grasping, manipulation, and object handling are very common due to an inability to manage the proper regulations of finger force, timing, and precision [7].

These impairments consequently make it very difficult for individuals with stroke to carry on with activities of daily living, such as feeding, dressing, grooming, and household tasks. Restricted upper limb function contributes to reduced participation in life within the home, work, and community, leading to limited social interactions and a poor overall sense of well-being [8]. The improvement of upper limb function, therefore, is at the core of rehabilitation concerns in stroke, since independence and quality of life are closely intertwined with upper limb capacity.

There is evidence that functional recovery of the affected upper limb can be improved when people with stroke have sufficient opportunity to engage in repetitive, task-oriented practice. Many rehabilitation strategies currently exist for upper limb impairments after stroke, including physiotherapy, occupational therapy, conductive education, splinting, casting, pharmacotherapy, and surgical interventions. Other specific therapeutic approaches that have been used in clinical practice include neurodevelopmental therapy and constraint-induced movement therapy [9]. Despite such a broad range of existing interventions, strong evidence supporting the superiority or long-term effectiveness of any single approach in ensuring meaningful functional recovery of the upper limb remains limited.

Within the last decade, virtual reality has become a unique and promising tool for neurorehabilitation. Virtual reality is usually understood to be a computer-generated, interactive simulation that allows users to explore and manipulate three-dimensional worlds similar in appearance to actual objects and events [10]. In rehabilitation contexts, VR enables patients to execute goal-directed movements in an engaging and motivating environment, with real-time visual and sensory feedback that might improve motor learning and neuroplasticity.

It has also been documented that VR for stroke rehabilitation can be interactive, enjoyable, and possibly effective for the enhancement of upper limb motor control and functional performance if used in sufficient intensity and duration [11]. For instance, VR-based therapy allows repetitive practice of functional movements within a controlled, adaptive environment that may surmount some limitations of conventional rehabilitation approaches. Additionally, most VR systems can be adjusted to match the individual's functional level, providing progressive challenges regarding task difficulty while encouraging the active participation of the patient.

Virtual reality-based therapy is one of the most innovative developments in rehabilitation technology and holds much promise for improving activities of daily living following stroke. An important advantage of VR-based interventions is their potential for various settings: rehabilitation clinics, nursing homes, and patients' homes. This flexibility allows for additional practice beyond formal therapy sessions, which may enhance functional outcomes and promote long-term recovery [12].

Despite the increased interest in rehabilitation using VR, few studies have investigated its efficacy in individuals with stroke, and this research is still at an early stage. Of particular note, there has been no investigation that focuses on the use and impact of virtual reality-based therapy in Saudi individuals with stroke. Considering the high incidence rate of stroke in Saudi Arabia and the fact that it plays a leading role in mortality, morbidity, and loss of functional independence, there arises an urgent need to explore innovative and effective rehabilitation intervention that can help improve upper function and ensure participation in activities of daily living.

Treatments that offer more rapid and effective improvement in upper limb performance are, therefore, of particular value to the Saudi stroke population. Virtual reality-enhanced physiotherapy may represent a useful adjunct or alternative to traditional rehabilitation by increasing patient motivation, therapy intensity, and functional improvement. This study was thus performed as an attempt to examine whether virtual reality-based therapy can be effectively used for the enhancement of upper limb function when compared to a traditional functional training program among Saudi patients with chronic stroke.

Methodology

Study Design: This study was designed as a two-armed controlled trial to evaluate the impact of Virtual Reality (VR)–integrated physiotherapy on upper limb performance in individuals with chronic stroke. Participants were allocated into experimental and control groups and assessed at baseline and after completion of the intervention.

Study Area: The study was conducted in the Department of Physical Medicine and Rehabilitation (PMR), Nalanda Medical College and Hospital, Patna, Bihar, India.

Study Duration: The study duration was 12 months.

Sample Size: The total sample size planned for the study was 52 participants. However, after screening and application of eligibility criteria, 30 participants (15 in both groups) who met the inclusion criteria were enrolled and completed the study.

Sample Population: Participants consisted of individuals diagnosed with chronic stroke attending the Department of PMR. A total of 52 stroke patients were initially screened, out of which 30 met the inclusion criteria. From these, 30 participants were finally recruited and allocated equally into experimental and control groups.

Inclusion Criteria

Participants were included in the study if they met the following criteria:

- Age between 50 and 60 years
- Diagnosed with chronic stroke (≥6 months post-stroke) due to ischemic or hemorrhagic etiology
- Upper limb spasticity graded 1, 1+, or 2 on the Modified Ashworth Scale
- Ability to extend the wrist by at least 20° and fingers by 10° from full flexion
- Cognitive ability to understand and follow instructions
- No participation in other interventions aimed at improving upper limb function during the study period

Exclusion Criteria

Participants were excluded if they had:

- Cognitive impairment with Mini-Mental State Examination score <23
- Fixed contractures or stiffness in shoulder, elbow, wrist, or finger joints
- Painful shoulder syndrome
- Major rotational malalignment of the affected upper limb
- Cardiac pacemaker
- Visual, auditory, or perceptual impairments
- Uncontrolled seizures
- History of botulinum toxin injection within 6 months prior to study
- Use of muscle-tone control medication within 3 months prior to study

Data Collection Methods: Data collection was carried out at baseline prior to the initiation of the intervention and immediately after completion of the treatment program. All assessments were conducted by trained assessors who were not involved in the treatment delivery and were blinded to group allocation to minimize assessment bias. Upper limb performance was evaluated using standardized and validated outcome measures, namely the Action Research Arm Test (ARAT), Wolf Motor Function Test (WMFT), and Hand Grip Strength (HGS). The ARAT was used to assess upper limb functional ability through tasks involving grasp, grip, pinch, and gross movements, with higher scores indicating better performance. The WMFT was administered to evaluate motor ability of the affected upper limb through timed and functional tasks, and the total score as well as the time taken to complete the tasks (WMFT-Time) were recorded. Hand grip strength of the affected upper limb was measured using a hand grip dynamometer, with higher post-treatment values reflecting improvement in muscular strength and functional capacity. All measurements were recorded systematically and consistently at both assessment points to allow accurate comparison of changes over time.

Procedure: After obtaining ethical approval and written informed consent, eligible participants were recruited from the Department of Physical Medicine and Rehabilitation, Nalanda Medical College and Hospital, Patna. Participants who met the inclusion criteria were allocated into experimental and control groups, each consisting of fifteen participants. Both groups received face-to-face individualized physiotherapy sessions three times per week for a duration of three months, with each session lasting two hours and a fifteen-minute rest interval between the first and second hours. The experimental group received a combined intervention consisting of conventional physiotherapy exercises, functional upper limb training, and virtual reality–based therapy using the Armeo Spring system. Conventional physiotherapy included muscle facilitation, proprioceptive neuromuscular facilitation, strengthening, stretching, and postural reaction exercises, while functional training emphasized reaching, grasping, manipulative activities, and performance of activities of daily living using the affected upper limb. The virtual reality component involved task-oriented upper limb exercises performed in a simulated environment with augmented feedback to enhance motor learning and engagement. The control group received a conventional functional physiotherapy program of equal duration, focusing on strengthening, facilitation, and functional task practice without the use of virtual reality. All interventions were supervised by qualified physiotherapists to ensure uniformity and adherence to the treatment protocol.

Statistical Analysis: Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) software, version 26. Descriptive statistics were used to summarize demographic and clinical characteristics of the participants. For parametric variables, including WMFT-Time and Hand Grip Strength, paired t-tests were used to analyze within-group differences between pre- and post-intervention scores, while independent t-tests were applied to compare differences between the experimental and control groups at baseline and post-intervention. For non-parametric variables, including ARAT and WMFT scores, within-group comparisons were analyzed using the Wilcoxon signed-rank test, and between-group comparisons were assessed using the Mann–Whitney U test. Results were expressed as mean ± standard deviation for parametric data and mean rank for non-parametric data. A p-value of less than 0.05 was considered statistically significant."

Result

Table 1 presents the demographic and clinical characteristics of participants in the experimental and control groups. The mean age was comparable between the experimental group (55.20 ± 3.38 years) and the control group (54.73 ± 3.61 years), with no statistically significant difference (p = 0.72). Sex distribution was similar in both groups (9 males/6 females in the experimental group versus 8 males/7 females in the control group; p = 0.71). The duration since stroke was also comparable between groups (11.40 ± 2.21 months vs. 11.13 ± 2.29 months; p = 0.75). There were no significant differences in the type of stroke, affected side, or baseline spasticity grade as measured by the Modified Ashworth Scale (MAS) (p > 0.05 for all). Overall, Table 1 indicates that both groups were well matched at baseline, ensuring that post-intervention differences could be attributed to the treatment effects rather than baseline variability.

Table 1: Demographic and clinical characteristics of participants

Variables	Experimental Group (n = 15)	Control Group (n = 15)	p-value
Age (years), Mean ± SD	55.20 ± 3.38	54.73 ± 3.61	0.72
Sex (Male/Female)	9/6	8/7	0.71
Duration since stroke (months), Mean ± SD	11.40 ± 2.21	11.13 ± 2.29	0.75
Type of stroke (Ischemic/Hemorrhagic)	10/5	9/6	0.71
Affected side (Right/Left)	8/7	7/8	0.72
Spasticity grade (MAS), Mean ± SD	1.53 ± 0.41	1.56 ± 0.43	0.83

Table 2 summarizes the within- and between-group differences in upper limb functional measures at baseline and after 12 weeks of treatment. At baseline, there were no significant differences between the control and experimental groups for ARAT (p = 0.94), WMFT (p = 0.91), WMFT-Time (p = 0.84), or hand grip strength (p = 0.86), indicating comparability between groups. Following 12 weeks of intervention, both groups showed significant within-group improvements in all outcome measures; however, the experimental group demonstrated more pronounced gains. Post-treatment ARAT and WMFT mean ranks were significantly higher in the experimental group compared to the control group (p = 0.004 and p = 0.002, respectively). The experimental group also showed a greater reduction in WMFT-Time (52.00 ± 8.96 vs. 65.10 ± 9.72 seconds; p = 0.002) and a significantly larger increase in hand grip strength (25.60 ± 3.78 vs. 20.20 ± 3.46 kg; p = 0.001). Overall, Table 2 indicates that while both interventions were effective, the experimental treatment resulted in significantly superior improvements in upper limb function after 12 weeks.

Table 2: Within- and between-group differences for upper limb functional measures at baseline and immediately after 12 weeks of treatment (N = 30)

Parameter	Control Group (n = 15)	Experimental Group (n = 15)	p-value
Action Research Arm Test (ARAT)			
Mean Rank – Pre	15.47	15.53	0.94
Mean Rank – Post	11.2	19.8	0.004*
p-value	0.003*	<0.001*	–
Wolf Motor Function Test (WMFT)			
Mean Rank – Pre	15.67	15.33	0.91
Mean Rank – Post	10.87	20.13	0.002*
p-value	0.002*	<0.001*	–
Wolf Motor Function Test–Time (seconds)			
Mean ± SD – Pre	81.20 ± 10.52	82.00 ± 10.88	0.84
Mean ± SD – Post	65.10 ± 9.72	52.00 ± 8.96	0.002*
p-value	0.003*	<0.001*	–
Hand Grip Strength (kg)			
Mean ± SD – Pre	15.90 ± 3.08	16.10 ± 3.25	0.86
Mean ± SD – Post	20.20 ± 3.46	25.60 ± 3.78	0.001*
p-value	0.002*	<0.001*	–

Table 3 presents the between-group comparison of post-treatment outcome measures following the intervention. The experimental group showed significantly higher ARAT scores (42.60 ± 4.72) compared to the control group (36.10 ± 5.06), indicating better upper limb functional ability (p = 0.001). Similarly, WMFT scores were significantly greater in the experimental group (54.00 ± 5.18) than in the control group (45.40 ± 5.62) (p < 0.001). The experimental group also demonstrated significantly faster task performance, as reflected by lower WMFT-Time values (52.00 ± 8.96 seconds) compared to the control group (65.10 ± 9.72 seconds) (p = 0.002). In addition, hand grip strength was significantly higher in the experimental group (25.60 ± 3.78 kg) than in the control group (20.20 ± 3.46 kg) (p = 0.001). Overall, Table 3 indicates that the experimental intervention resulted in superior post-treatment functional outcomes compared to the control condition.

Table 3: Between-group comparison of post-treatment outcome measures

Outcome Measure	Experimental Group (n = 15) Mean ± SD	Control Group (n = 15) Mean ± SD	p-value
ARAT (score)	42.60 ± 4.72	36.10 ± 5.06	0.001*
WMFT (score)	54.00 ± 5.18	45.40 ± 5.62	<0.001*
WMFT-Time (sec)	52.00 ± 8.96	65.10 ± 9.72	0.002*
Hand Grip Strength (kg)	25.60 ± 3.78	20.20 ± 3.46	0.001*

Table 4 shows the mean change in outcome measures after 12 weeks of intervention in experimental and control groups. The experimental group demonstrated significantly greater improvement in upper limb function, with a higher increase in ARAT scores (+13.20 ± 3.08) compared to the control group (+6.00 ± 2.94), which was statistically significant (p < 0.001). Similarly, improvements in WMFT scores were markedly higher in the experimental group (+17.00 ± 3.88) than in the control group (+8.20 ± 3.64) (p < 0.001). A greater reduction in task completion time on the WMFT was also observed in the experimental group (−30.00 ± 8.42 seconds) compared to controls (−16.10 ± 7.86 seconds), indicating faster performance, with a significant difference (p = 0.002). Additionally, hand grip strength improved significantly more in the experimental group (+9.50 ± 2.76 kg) than in the control group (+4.30 ± 2.38 kg) (p = 0.001). Overall, Table 4 demonstrates that experimental intervention was more effective than the control in improving functional outcomes after 12 weeks.

Table 4: Mean change (Post–Pre) in outcome measures after 12 weeks of intervention

Outcome Measure	Experimental Group Mean Change ± SD	Control Group Mean Change ± SD	p-value
ARAT (score)	+13.20 ± 3.08	+6.00 ± 2.94	<0.001*
WMFT (score)	+17.00 ± 3.88	+8.20 ± 3.64	<0.001*
WMFT-Time (sec)	−30.00 ± 8.42	−16.10 ± 7.86	0.002*
Hand Grip Strength (kg)	+9.50 ± 2.76	+4.30 ± 2.38	0.001*

Discussion

The findings of the present study showed that virtual reality-integrated physiotherapy significantly improved the performance of the upper limb in chronic stroke patients more than that of conventional physiotherapy alone. The within-group analyses of variation demonstrated that both experimental and control groups had significant improvements in the scores of the Action Research Arm Test, Wolf Motor Function Test, time taken to perform the tasks of WMFT, and hand grip strength after the 12-week intervention. These gains were significantly higher for participants who underwent virtual reality-based therapy compared with those receiving conventional physiotherapy across all outcomes-an indicator of the potential of immersive and interactive rehabilitation modalities toward promoting motor recovery after stroke."

The superior results found among the experimental group can be partly explained by the better engagement, intensity, and task-oriented training that virtual reality-based therapy can provide. Indeed, virtual reality offers enriched sensorimotor feedback and promotes active repetition, a critical component for neuroplasticity and motor relearning, by allowing stroke survivors to practice meaningful motor tasks in immersive, motivating environments (Dobkin, 2004; Merians et al., 2002) [13,14]. Our results support previous studies showing the superiority of virtual reality interventions on enhancing upper limb motor function compared with conventional physiotherapy. For instance, Merians et al. (2002) [14] demonstrated significant improvement in ARAT and WMFT scores after virtual reality-based therapy compared with standard therapy, and highlighted that repetitive, goal-directed movements within virtual environments might hasten functional recovery. Similarly, Kwakkel et al. (2008) [15], and Basteris et al. (2014) [16] found larger improvements in motor function after robot-assisted and virtual reality-based upper limb rehabilitation as compared with conventional therapy, especially when interventions involved high-intensity, task-specific practice and real-time feedback.

The advantage of virtual reality-based therapy is further supported by the observed improvements in movement speed and hand grip strength. The reduction in completion times of the WMFT in the experimental group reflects increased coordination, movement efficiency, and motor control, in support of prior studies that have shown that virtual reality can enhance temporal and spatial aspects of upper limb movements in chronic stroke (Beer et al., 2007) [17]. The significant increase in hand grip strength in the experimental group corroborates findings from Kim et al. (2018) [9], where the authors reported that low-cost Kinect-based virtual rehabilitation systems facilitated significant gains in grip force and functional hand use compared to conventional therapy. These functional improvements are particularly pertinent given that weakness and limited hand function are major contributors to activity limitation in stroke survivors (Ada & Canning, 2005) [18].

Despite these consistent findings, some studies have shown more modest effects of virtual reality interventions. Crosbie et al. (2007) [12] noted that in some populations, virtual reality alone might not yield significantly better results than conventional therapy, especially if the training duration or intensity is limited. Similarly, Holden et al. (2007) [19] pointed out that although virtual reality environments enhance engagement and repetition, they require careful tailoring to individual patient capabilities in order to obtain optimal functional gains. The inconsistent findings between studies also may reflect differences in stroke chronicity, severity of upper-limb impairment, and the specific design of virtual reality tasks. Our participants had a mean stroke duration of approximately 11 months; this suggests that virtual reality interventions can produce clinically meaningful functional recovery even during the chronic phase, in line with Levac et al. (2019) [20] who obtained sustained motor improvements in chronic stroke patients after immersive task-oriented training.

The comparable baseline characteristics between groups in the current study, such as age, sex distribution, stroke type, affected side, and spasticity levels, support the external validity of the treatment effects observed. The mean Modified Ashworth Scale scores in both groups indicated mild spasticity, which suggested that participants could actively engage in performing repetitive movements without excessive resistance; this might have been the facilitating factor in the benefits of virtual reality-based therapy. Participant selection and the baseline motor function of the participants have also been pointed to in prior studies as a consideration in the responsiveness to a virtual reality intervention (Sisto et al., 2002) [10]. Besides, the implementation of several outcome measures such as ARAT, WMFT, and hand grip strength allowed detailed assessment of motor performance, functional ability, and strength, in agreement with suggestions by Dandekar and Ganvir, 2019 [21], and Nijland et al., 2010 [22], regarding the assessment of upper limb recovery after stroke.

These findings point out the clinical relevance of implementing virtual reality in physiotherapy practices for stroke rehabilitation. Virtual reality-based interventions allow patients to engage in repetitive and task-oriented practice in an increasingly controlled but stimulating environment, thereby overcoming the learned non-use phenomenon and resulting in improved neuromuscular recovery of the affected limb (Botte et al., 1988; Feys et al., 1998) [23,24],. However, it is fair to highlight that conventional physiotherapy also ensured significant benefits, thus strengthening the role of traditional physiotherapy approaches in promoting upper limb recovery. Therefore, conventional physiotherapy associated with the application of virtual reality may achieve synergistic effects by maximizing functional improvement due to increased motivation, task variability, and enhanced feedback.

Overall, the study indicates that virtual reality-integrated physiotherapy surpasses conventional therapy in improving upper limb motor function, movement efficiency, and hand strength in chronic stroke survivors. These results concur with previous studies indicating enhanced neuroplasticity and functional recovery when patients are exposed to immersive, goal-directed, and repetitive practice in enriched environments. Long-term effects of virtual reality-based therapy, optimal intervention duration, and applicability across the different stages of stroke should be further tested in future studies to develop the most appropriate rehabilitation strategies for optimizing upper limb recovery.

Conclusion

The results of this randomized controlled trial show that virtual reality–integrated physiotherapy further improves upper limb performance in patients with stroke compared with conventional physiotherapy. Both groups realized significant improvement throughout the intervention period and attest to the effectiveness of structured rehabilitation; however, participants receiving virtual reality–integrated physiotherapy showed greater enhancement in upper limb function, motor performance, movement efficiency, and hand grip strength. The comparable baseline demographic and clinical characteristics between groups add validity to these findings, suggesting that the observed benefits of such intervention are due to it per se. A virtual reality–based approach seems more effective and engaging as a rehabilitation strategy, providing added value in facilitating functional recovery of the upper limb after stroke.

References

1. Sabut SK, Sikdar C, Mondal R, Kumar R, Mahadevappa M. Restoration of gait and motor recovery by functional electrical stimulation therapy in persons with stroke. Disability and rehabilitation. 2010 Jan 1;32(19):1594-603.
2. Sacco RL, Kasner SE, Broderick JP, Caplan LR, Connors JJ, Culebras A, Elkind MS, George MG, Hamdan AD, Higashida RT, Hoh BL. An updated definition of stroke for the 21st century: a statement for healthcare professionals from the American Heart Association/American Stroke Association. Stroke. 2013 Jul;44(7):2064-89.
3. Langhorne P, Bernhardt J, Kwakkel G. Stroke rehabilitation. The Lancet. 2011 May 14;377(9778):1693-702.
4. Qureshi S. Saudi Stroke Association: prospects and achievements. International Journal of Stroke. 2008 Aug;3(3):219-20.
5. Al Khathaami AM, Algahtani H, Alwabel A, Alosherey N, Kojan S, Aljumah M. The status of acute stroke care in Saudi Arabia: an urgent call for action. International Journal of Stroke. 2011 Feb;6(1):75-6.
6. Guy S, Clarke L, Bryant H, Robinson G, Segaran E, Losseff N, Stewart T. An interdisciplinary team approach to acute stroke rehabilitation. Neurol Rehabil Stroke. 2004:26-56.
7. Gordon AM, Lewis SR, Eliasson AC, Duff SV. Object release under varying task constraints in children with hemiplegic cerebral palsy. Developmental medicine and child neurology. 2003 Apr;45(4):240-8.
8. Sköld A, Josephsson S, Eliasson AC. Performing bimanual activities: the experiences of young persons with hemiplegic cerebral palsy. The American journal of occupational therapy. 2004 Jul 1;58(4):416-25.
9. Sakzewski L, Ziviani J, Boyd R. Systematic review and meta-analysis of therapeutic management of upper-limb dysfunction in children with congenital hemiplegia. Pediatrics. 2009 Jun 1;123(6):e1111-22.
10. Sisto SA, Forrest GF, Glendinning D. Virtual reality applications for motor rehabilitation after stroke. Topics in stroke rehabilitation. 2002 Jan 1;8(4):11-23.
11. Kim WS, Cho S, Park SH, Lee JY, Kwon S, Paik NJ. A low cost kinect-based virtual rehabilitation system for inpatient rehabilitation of the upper limb in patients with subacute stroke: A randomized, double-blind, sham-controlled pilot trial. Medicine. 2018 Jun 1;97(25):e11173.
12. Crosbie JH, Lennon S, Basford JR, McDonough SM. Virtual reality in stroke rehabilitation: still more virtual than real. Disability and rehabilitation. 2007 Jan 1;29(14):1139-46.
13. Dobkin BH. Strategies for stroke rehabilitation. The Lancet Neurology. 2004 Sep 1;3(9):528-36.
14. Merians AS, Jack D, Boian R, Tremaine M, Burdea GC, Adamovich SV, Recce M, Poizner H. Virtual reality–augmented rehabilitation for patients following stroke. Physical therapy. 2002 Sep 1;82(9):898-915.
15. Kwakkel G, Kollen BJ, Krebs HI. Effects of robot-assisted therapy on upper limb recovery after stroke: a systematic review. Neurorehabilitation and neural repair. 2008 Mar;22(2):111-21.
16. Basteris A, Nijenhuis SM, Stienen AH, Buurke JH, Prange GB, Amirabdollahian F. Training modalities in robot-mediated upper limb rehabilitation in stroke: a framework for classification based on a systematic review. Journal of neuroengineering and rehabilitation. 2014 Jul 10;11(1):111.
17. Beer RF, Ellis MD, Holubar BG, Dewald JP. Impact of gravity loading on post-stroke reaching and its relationship to weakness. Muscle & Nerve: Official Journal of the American Association of Electrodiagnostic Medicine. 2007 Aug;36(2):242-50.
18. Ada L, Canning C. Changing the way we view the contribution of motor impairments to physical disability after stroke. Science-based Rehabilitation, Theories into Practice. 2005 Jan 1:87-106.
19. Holden MK, Dyar TA, Dayan-Cimadoro L. Telerehabilitation using a virtual environment improves upper extremity function in patients with stroke. IEEE transactions on neural systems and rehabilitation engineering. 2007 Mar 12;15(1):36-42.
20. Levac DE, Huber ME, Sternad D. Learning and transfer of complex motor skills in virtual reality: a perspective review. Journal of neuroengineering and rehabilitation. 2019 Oct 18;16(1):121.
21. Dandekar SP, Ganvir S. Action research arm test as a tool for assessment of motor recovery in patients with stroke: a critical review. Int. J. Res. Med. Sci. 2019 Aug; 7:3224-9.
22. Nijland R, van Wegen EE, Verbunt J, van Wijk R, van Kordelaar J, Kwakkel G. A comparison of two validated tests for upper limb function after stroke: The Wolf Motor Function Test and the Action Research Arm Test. Journal of rehabilitation medicine. 2010;42(7):694-6.
23. BOTTE MJ, NICKEL VL, AKESON WH. Spasticity and Contracture Physiologic Aspects of Formation. Clinical Orthopaedics and Related Research (1976-2007). 1988 Aug 1; 233:7-18.

24. Feys HM, De Weerdt WJ, Selz BE, Cox Steck GA, Spichiger R, Vereeck LE, Putman KD, Van Hoydonck GA. Effect of a therapeutic intervention for the hemiplegic upper limb in the acute phase after stroke: a single-blind, randomized, controlled multicenter trial. Stroke. 1998 Apr;29(4):785-92.