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Ocena czynników wpływających na skuteczność terapii integracji sensorycznej u dzieci w wieku przedszkolnym i wczesnoszkolnym

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Effectiveness of reinforced feedback in virtual environment for upper limb rehabilitation in acute stroke

Skuteczność wzmocnionego sprzężenia zwrotnego w wirtualnym środowisku dla rehabilitacji kończyny górnej w ostrym udarze

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Abstract

Background. Motor impairments following stroke result in loss of upper extremity function which is often persistent and disabling. Reinforced feedback in the virtual environment (RFVE) could activate mirror neuron systems which are stimulated during action observation and action execution. This study aims to evaluate the activation of proximal muscles in paretic upper limb following RFVE training.
Methodology. Twenty-four stroke patients were included in the study, 12 in control group received impairment specific training and 12 in experimental group received RFVE training using Oculus quest 2 in addition to impairment specific exercise training. Surface electromyography (SEMG) of shoulder muscles of affected upper limb were recorded in both groups. Arm motor recovery was recorded using Chedoke - McMaster stroke assessment scale (CMSA).
Results. Paired t-test was used to analyze the results within the group which showed improvement in the both groups and unpaired t-test was used to test the outcomes between the groups where RFVE group showed significant improvement in average muscle activity in anterior deltoid, middle deltoid and CMSA scores than control group ($p < 0.005$*).
Conclusion. The results of this study demonstrated the beneficial effects of RFVE in upper limb training which showed improvements in muscle activation in SEMG and arm recovery in CMSA scores. RFVE training is a safe and well-accepted effective intervention in acute stroke rehabilitation that could become a successful intervention for early functional recovery.

Keywords

upper limb dysfunction, acute stroke, virtual reality, visual feedback, SEMG

Streszczenie

Tło. Zespół cieśni nadgarstka (CTS) jest znaczącym problemem zdrowotnym, który może ograniczać aktywność i zdolności kobiet w okresie połogu zarówno w życiu osobistym, jak i zawodowym. Cel. Porównanie skuteczności terapii laserem niskiej mocy (LLLT) i ultradźwięków pulsacyjnych (US) w łagodzeniu objawów CTS po porodzie. Metody. Czterdzieści osiem kobiet z łagodnym do umiarkowanego CTS zostało podzielonych na trzy grupy. Oprócz ćwiczeń nadgarstka, grupa (A) (n = 16) otrzymała terapię laserem niskiej mocy, grupa (B) (n = 16) otrzymała ultradźwięki pulsacyjne, a grupa (C) (n = 16) wykonywała tylko ćwiczenia nadgarstka. Dla wszystkich grup, zabiegi były aplikowane na dotkniętą rękę, trzy sesje tygodniowo przez cztery tygodnie. Wszystkie kobiety po porodzie były oceniane przed i po terapii za pomocą wizualnej skali analogowej (VAS) dla intensywności bólu, Kwestionariusza Bostońskiego na CTS (BCTS) dla diagnozy objawów CTS, elektromiografii dla pomiaru prędkości przewodzenia motorycznego (MCV) i czuciowego (SCV), motorycznego opóźnienia dystalnego (MDL) oraz szczytowego opóźnienia czuciowego (SPL), oraz dynamometru chwytu ręki dla oceny siły chwytu ręki. Wyniki. Wszystkie zmierzone parametry wykazały znaczącą poprawę we wszystkich trzech grupach po terapii w porównaniu do stanu przed terapią. Porównanie międzygrupowe wykazało wysoce znaczący spadek wartości VAS, BCTS i SPL oraz znaczący wzrost SCV i siły chwytu ręki między grupami A i C na korzyść grupy A oraz między grupami B i C na korzyść grupy B, podczas gdy znaczące zmiany w MDL i MCV zaobserwowano tylko między grupami A i C na korzyść grupy A ($p < 0,05$), bez znaczących różnic we wszystkich mierzonych parametrach między grupami A i B ($P > 0,05$). Wnioski. Zarówno terapia laserem niskiej mocy, jak i ultradźwięki pulsacyjne są skutecznymi metodami, które mogą być stosowane jako efektywna terapia zachowawcza w łagodzeniu objawów CTS po porodzie.

Słowa kluczowe

dysfunkcja kończyny górnej, ostry udar, rzeczywistość wirtualna, sprzężenie zwrotne wzrokowe, SEMG

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Introduction

Stroke is one of the most serious, devastating, and debilitating diseases, rated as the second leading cause of death worldwide. Stroke results in chronic disability which could be due to cerebral infarction, intracerebral hemorrhage, intraventricular hemorrhage, and subarachnoid hemorrhage [1]. The most common stroke groups are small-vessel stroke (12.8%), brainstem stroke (11.4%), and middle cerebral artery (MCA) stroke (50.8%) where the patients predominantly present with upper limb dysfunction [2]. Epidemiological data indicate that deaths due to neurological disorders are predominantly by stroke (68%), followed by Alzheimer's and dementias (12%), and encephalitis (5%).

Common risk factors for stroke are low physical activity, high body-mass index, high fasting plasma glucose, high systolic blood pressure, high cholesterol, alcohol consumption, tobacco smoking, kidney dysfunction, and dietary risks [3]. Personal habits and dietary risks are the most significant modifiable factors that can help reduce the increasing prevalence of stroke. The primary poststroke symptoms vary depending on the location and severity of brain lesions resulting in motor, sensory and cognitive impairment. Secondary functional impairments include loss of vision and/or speech, balance issues leading to increased fall risk, and difficulties in daily activities [4].

Motor impairments following stroke, affecting about 80% of patients, result in a loss of control over one side of the body, including the face, arm, and leg [5]. Patients with MCA territory involvement have the lowest functional recovery. Left-sided MCA lesions, associated with aphasia and apraxia, lead to prolonged retraining periods or delays in learning compensatory techniques. Conversely, right-sided MCA lesions, associated with neglect and agnosia, can result in frustration and hinder their learning process [6].

The prevalence of upper limb impairment in the acute phase of stroke, is about 50–80% and 40–50% in the chronic phase [7, 8]. Paresis, abnormal muscle tone, decreased somatosensation, and coordination are the commonly seen upper limb impairments after stroke [9]. This leads to difficulty in moving and coordinating the arms, hands and fingers, resulting in difficulty carrying out daily activities such as eating, dressing and washing. Maximum recovery of dexterity is expected within first six months of upper limb motor dysfunction post stroke [10].

Stroke rehabilitation focuses on the recovery of impaired movements and their associated functions. Recent advances in rehabilitation proved to improve the quality of life of the patient in terms of independence in activities of daily living through functional tasks training that enhances neuroplasticity and helps fasten the recovery. Research with moderate-quality evidence showed that beneficial effects are noted in constraint-induced movement therapy, mirror therapy, mental practice, repetitive task practice, and virtual reality [11].

Recent technologies like virtual reality (VR) have paved in the way with active patient participation in stroke rehabilitation. VR is created with computer hardware and software to provide an interactive simulated practice environment and feedback on the execution of movement or goal attainment, or both through which new motor skills are learned [12, 13]. Two principles of game design that are highly relevant to rehabilitation are meaningful play and challenges for scaffolding skill improvement which enables the clinician to measure kinematic and kinetic measures of patient's current performance precisely [14, 15]. VR induces long-term functional plasticity through repetitive practice and new skill acquisition. VR with multisensory feedback enhances the rehabilitation process when administered with conventional therapy, thereby promoting motor learning [16].

VR rehabilitation is based on the human mirror neuron system which is active during both goal-oriented action execution and action observation. Mirror neurons in the human brain are activated when a person performs a task or when a person looks at someone else performing a task [17]. The strength of mirror neuron activation is found to be stronger during both action imitation and action observation and was associated with additional activation in medial temporal areas, superior parietal lobule, and the prefrontal cortex. It is a key neural structure for relearning the impaired motor functions following brain damage such as stroke [18]. The goal of an action is more important than the method of its execution for mirror neuronal activation. The task-oriented exercises in virtual environment in turn activate the motor cortex strongly which leads to cortical facilitation [19]. Visual feedback reinforced in virtual environment can facilitate visuomotor processing in rehabilitation through action observation, and action planning.

VR can be categorized into two forms: immersive and non-immersive. Non-immersive virtual reality is a type in which patients interact with a virtual environment usually through a computer whereas in fully immersive VR, special equipment like VR glasses, gloves, and body sensors are required to provide a real-time virtual experience. The recovery rate in stroke can be slow, potentially due to a lack of active participation in the exercise program. Reinforced feedback in a virtual environment (RFVE) using gaming tasks can enhance patient motivation during rehabilitation, thereby improving efficiency and motor performance. VR training has also been proven to result in very high patient satisfaction [20, 21]. Immersive VR training combined with computer-based cognitive rehabilitation has a significant effect on visual attention and short-term visuospatial memory in stroke patients with cognitive impairment [22].

Literature shows that non-immersive VR has been incorporated from the subacute to chronic stages in stroke patients, but it faces practical constraints in the acute stage. RFVE, an immersive form of VR, involves giving subjects with a paretic hand virtual tasks displayed on a head mount. This visual encouragement in the acute phase can lead to improved motor activity. RFVE in combination with standard physiotherapy regimes may result in improvements in motor control, range of motion, and functional recovery at the shoulder [23].

Motor recruitment in acute stroke conditions can be identified with surface electromyography (SEMG) when it is not clinically evident. SEMG is a non-invasive window into the nervous system which provides details on muscle activity [24]. Translation of electromyography (EMG) into stroke rehabilitation in acute care is used for monitoring daily updates on changes in

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muscle activity, diagnosis, or biofeedback [25]. SEMG is commonly studied in the deltoid and the upper trapezius muscles because they are superficial for easier recording and likely to show activity with minimal effort. Hence this study intends to analyze the effectiveness of RFVE in activating upper limb function in acute stroke measured using SEMG.

Methodology

The ethics committee Sri Ramachandra Institute of Higher Education and Research, approved this interventional study (CSP/22/APR/109/310). Subjects were recruited from Sri Ramachandra Hospital, Neurology in patient wards. 12 subjects in each group were included based on the criteria. Subjects who had experienced first ischemic MCA stroke within 5 days of diagnosis, who were able to comprehend oral commands and had Brunnstrom staging of voluntary control at 1or 2 were included. Subjects were excluded if they had orthopaedic or other neurological impairments, or visual/hearing deficits that could limit the outcome of the study.

Instrumentation

Immersive virtual reality rehabilitation system

RFVE was administered using the Oculus Quest 2, an immersive gaming technology that allows virtual scenarios to be mirrored on a laptop screen. The VR intervention consists of playing games, ranging from virtual reaching and tracking tasks to more challenging upper limb activities. The device records the user's body movements, projects them in real time to the head-mount, and then allows the user to interact with virtual surroundings and objects while being immersed. Feedback is provided through visual and auditory stimuli. The user interacts with the environment using a simple controller device, which provides haptic (touch) feedback, along with software that allows therapists to guide the tasks. [12, 26].

Surface electromyogram (SEMG)

SEMG data are recorded using Neurotrac software 5.0.120. SEMG is a non-invasive tool and a widely used technology in rehabilitation research and provides quantifiable information on the myoelectric output of a muscle. Bipolar SEMG, which involves applying two adjacent electrodes between the innervation zone and in alignment with the muscle fiber direction, was used to measure muscle activations. The peak amplitude of EMG signals was recorded at baseline and post-intervention.

EMG recording

Muscle activity was recorded from the upper trapezius, anterior deltoid, and middle deltoid. Silver chloride adhesive electrodes were used. The basic guidelines for electrode placement were as described by the SENIAM project (Surface Electromyography for the Non-Invasive Assessment of Muscles). The active electrodes were placed on the muscle belly of the above muscles using standard skin preparation techniques with an inter-electrode spacing of 20 mm along an axis parallel to the muscle fibers. The skin was prepared by cleaning with 70% alcohol (ethanol). The ground electrode was placed on the C_7 spinous process (seniam.org). SEMG was recorded from the affected upper extremity when attempted to produce the movements. Adequate rest was given between each movement and SEMG unit recorded both peak and average readings for each test movement.

Chedoke–McMaster Stroke Assessment (CMSA) scale

This scale is utilized in individuals following stroke for screening and as an assessment tool to measure the physical impairment and activity. The CMSA consists of two inventories.
• Impairment inventory
• Activity Inventory

Impairment inventory evaluates 6 domains (shoulder pain, stages of recovery of postural control, arm, hand, leg, and foot). The arm domain was used in this study which was a 7-point scale used to score arm recovery.

Procedure

Subjects who met the inclusion criteria and provided informed consent (or received consent from their caregivers, if applicable) participated in the study. Subjects were allocated into conventional and intervention groups based on the lot method. All subjects were assessed with the CMSA for staging arm motor recovery, and muscle activation in the anterior deltoid, middle deltoid, and upper trapezius was recorded with SEMG. The conventional group was given impairment-specific exercises as described in Table 1, while the interventional group received RFVE training as detailed in Table 2, along with conventional exercises for 5 days. Intervention with RFVE exercise:
• Patient was in a supported sitting position and provided with a head mount of Oculus quest to experience an immersive environment.
• Tasks that demand upper limb muscle activity to accomplish it were selected and explained to the patient first.
• A duplicate controller was either given to or strapped onto the affected arm of the patient, while the therapist operated the real controller to perform the virtual tasks.
• Then by providing auditory cues with haptic feedback, the therapist performs the movement demanded by the game which provides visual feedback to the patient thereby facilitating muscle activation of the affected upper limb.
• The gaming was given as 2 mins per task and 1 min interval. Similarly, 10 sessions were practiced.
• Clapping and cheers were done for patients to participate enthusiastically in the rehabilitation

The first 5 minutes in the initial sessions were allowed for free practice for patients to warm up and familiarize themselves with the program. The second 5 minutes are for patients to become aware of the virtual environment. The remaining duration was used to motivate the patient to engage in the therapy, with visual feedback encouraging them to observe the task and initiate movement. The interventional group received 25 to 30 minutes of RFVE therapy for the upper extremity once a day for 5 days along with conventional exercises. The patients who accomplished the basic level were trained with progressive games. Treatment duration for both the groups was 1hr session per day. CMSA scores and SEMG was recorded in both groups in the paretic upper extremity after 5 sessions of therapy.

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Table 1. Conventional exercises

Sl. no	Starting position	Conventional exercises
1	In lying	• Passive movements to the paretic upper limb and lower limb. • Facilitating techniques by tapping on the muscle belly to improve muscle activity and control. • Active assisted exercises to the upper and lower limb. • Bed mobility training: Pelvic bridging exercises. • Supine to side lying, lying to sitting.
2	In sitting	• Weight-bearing to the paretic upper limb. • Supported shoulder exercises.

Table 2. RFVE training

Sl. no	Game	Description	Duration
1	First steps VR Oculus quest 2	Upper limb movements are encouraged using different objects such as cubes, paper rockets, and balls which can be manipulated and moved.	20 mins with 2 rest intervals in between the session
2	Progression Oculus first contact	Progressively more skill is required to handle different objects similar to the real environment	5 mins

Figure 1. Oculus Quest 2 device mirrored in the laptop screen

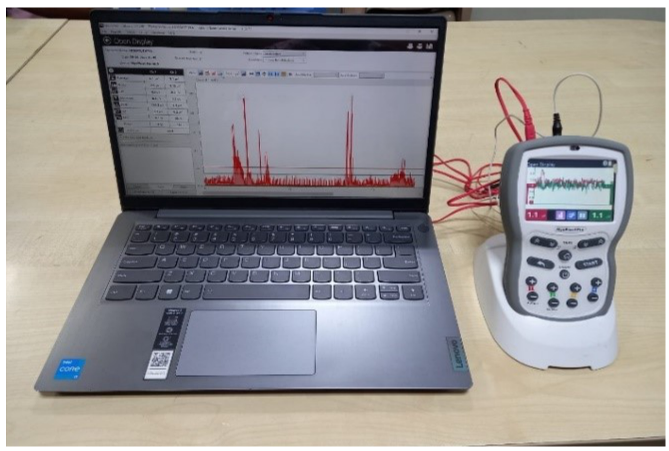

Figure 2. Neurotrac software 5.0.120 with system output

Figure 3. RFVE training in acute setup

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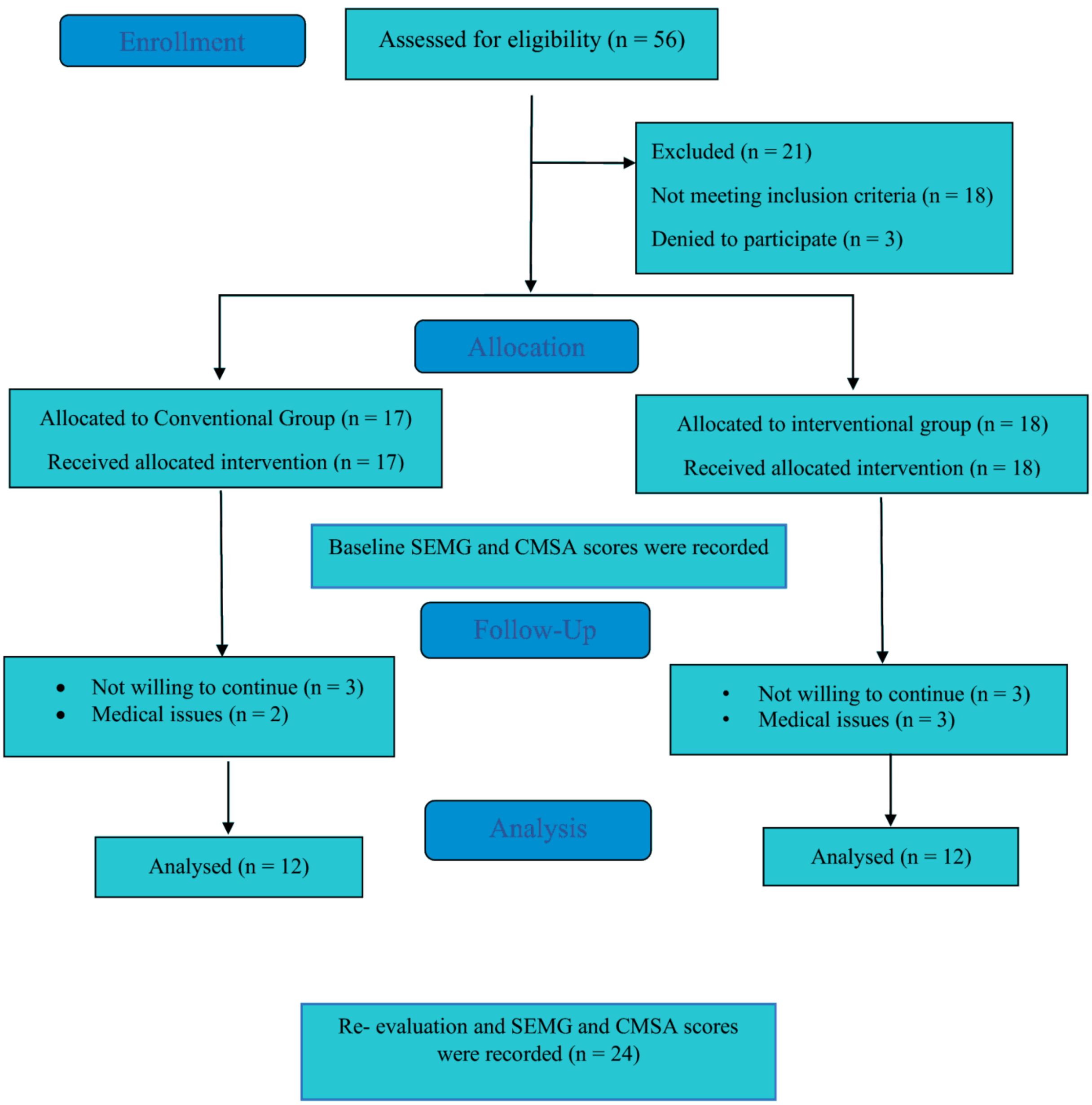

Figure 4. Consort flow diagram

Results

Statistical analysis was performed with SPSS version 21.0 software. 24 participants participated in this study and baseline characteristics are shown in Table 3. Patients with right CVA were higher in the study and no significant differences were found in the age of the study population. Paired t test showed statistically significant differences in SEMG and CMSA scores within the group (Table 4). Unpaired t test showed significant differences in the SEMG of the anterior and middle deltoid muscle groups and CMSA scores in the RFVE groups (Table 5).

Table 3. Baseline characteristics

Variables	Control Group (n = 12)	Experimental group (n = 12)
Ages in years [Mean (SD)]	55.08 (15.09)	53.08 (13.81)
Gender [Male / Female]	9 / 3	7 / 5
CVA [Right / Left]	7 / 5	9 / 3
CMSA [Grade 1 / Grade 2]	7/5	9/3
Brunnstrom [stage 1 / stage 2]	7/5	6/6

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Table 4. Comparison of average EMG of upper limb muscles and CMSA scores within the groups

Group	Average EMG	Pre-mean (SD)	Post-mean (SD)	p-value
Control	Anterior deltoid	13.4 (3.18)	16.85 (5.28)	0.026*
	Middle deltoid	14.9 (3.24)	19.79 (4.81)	0.013*
	Upper trapezius	14.76 (5.61)	17.18 (4.56)	0.263
	CMSA	1.41(0.49)	2.08(0.51)	0.006*
Intervention	Anterior deltoid	13.9 (5.28)	20.33 (6.058)	< 0.001*
	Middle deltoid	15.27 (6.44)	24.7 (3.95)	0.005*
	Upper trapezius	15.5 (3.27)	17.02 (8.22)	0.563
	CMSA	1.25 (0.45)	2.66 (0.65)	0.007*

Paired t test p < 0.05 significant*

Table 5. Comparison of post means of average SEMG and CMSA between the groups

	Control Mean (SD)	Intervention Mean (SD)	p-value
Anterior deltoid	16.85 (5.28)	20.33 (6.058)	0.022*
Middle deltoid	19.79 (4.81)	24.7 (3.95)	0.012*
Upper trapezius	17.18 (4.56)	17.02 (8.22)	0.954
CMSA	2.08 (0.51)	2.66 (0.65)	0.023*

Unpaired t test p < 0.05 significant*

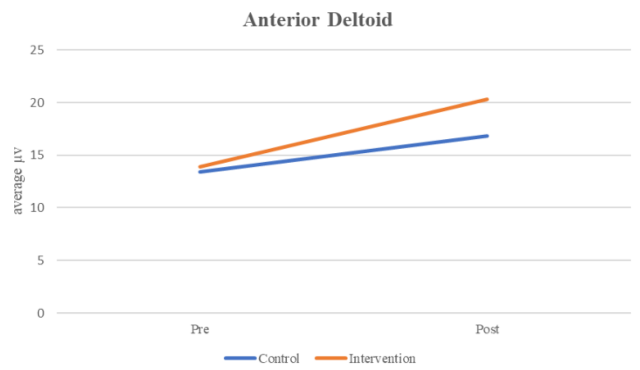

Figure 5. Comparison of average SEMG of anterior deltoid pre and post intervention for both group

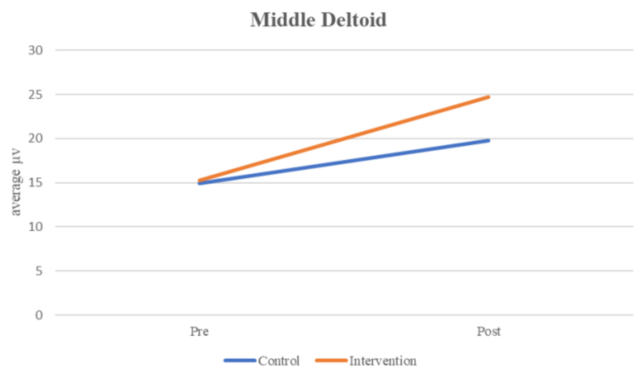

Figure 6. Comparison of average SEMG of middle deltoid pre and post intervention for both group

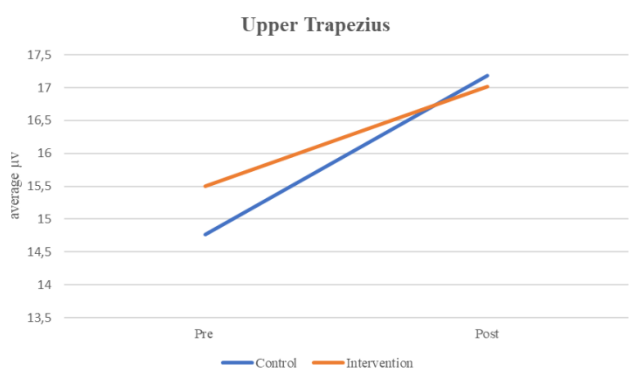

Figure 7. Comparison of average SEMG of upper trapezius pre and post intervention for both group

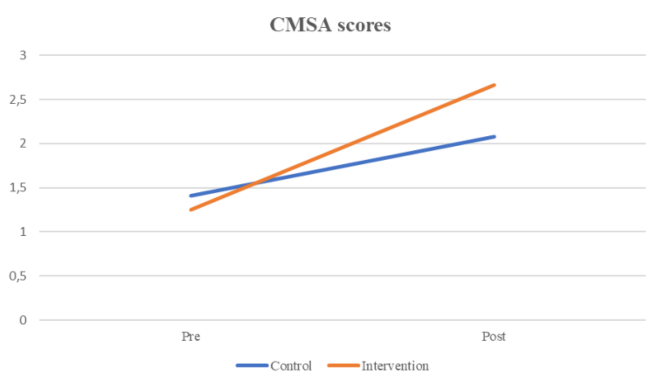

Figure 8. Comparison of CMSA scores pre and post intervention for both group

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Discussion

Upper limb function depends on proximal stability, distal mobility, and coordination between both upper limbs, all of which are often impaired in stroke. This impairment affects activities of daily living due to decreased motor control. The core element of rehabilitation in post-stroke is to maximize upper limb function thereby improving recovery and personal activities such as feeding, dressing, and grooming [11]. Adherence to exercises is often reduced due to secondary impairments in the acute phase of stroke, leading to a lack of active participation. In contrast, RFVE can increase exercise adherence with minimal caregiver assistance, compared to conventional training, thereby resulting in early learning and improvement. 12 subjects in conventional and 12 subjects in interventional group participated in the acute phase of stroke to evaluate the effect of RFVE.

RFVE provides subjects with appropriate artificially-enhanced feedback on the nature of the movement which involves knowledge of performance and some variables of outcome focusing on knowledge of results. This may help to temporarily or permanently improve motor performance and motor learning, thereby facilitating the acquisition of new motor skills in post-stroke patients [27]. Visual feedback given by virtual environment along with the haptic feedback by the controller on a specific task allows the subject to actively participate and makes the experience more immersive and entertaining.

The fundamental organization principle of the human brain is through the incoming visual, somatosensory and vestibular information about each half of the body which is projected to representations in the primary sensory cortex of the contralateral cerebral hemisphere. This incoming information is projected to the poly-sensory parietal cortex, which constructs a coherent body image leading to goal-directed motor behavior [28, 29]. The rostral part of the inferior parietal lobule and the lower part of the precentral gyrus along with the posterior part of the inferior frontal gyrus regions form the core of the human mirror-neuron system. Functional neuroimaging studies revealed that action generation shares the same parietal and premotor areas as action observation [30, 31].

Visual feedback, provided by the attempts of therapist encouraged the subjects to perform upper limb movements consistent with the virtual tasks visualised such as reaching for objects at various angles and holding them at specific ranges. This approach could enhance the patient's performance by improving movement control and activating specific muscle groups. Activation of proximal muscle groups was observed in both conventional and RFVE groups, even when the patients were initially flaccid following stroke. This is in concordance with the study done by Steele K M (2020) where EMG showed quantitative improvement in upper limb muscle activity in the acute phase following EMG biofeedback training [24]. Slater (1999) suggested that the sensory information generated in the virtual environment produces the sense of physical presence in that environment, domination of the virtual environment over the real world and visualizing an actual location rather than a compilation of computer-generated images and sounds [32]. Selective attention is more pronounced in the immersive form of VR which was found to be significant for performing in virtual environment as denoted by Witmer and Singer (1998) [33].

RFVE group showed increased activation of anterior deltoid and middle deltoid than conventional group which could be due to repeated attempts of affected upper limb to perform the movement following visual feedback encouraging motor learning in acute stroke. Gangitano et al. (2001) recorded motor evoked potentials (MEPs) from the hand muscles of normal individuals when they were observing grasping movements made by another individual. The MEPs were recorded at different intervals from the onset of the movement and the results showed that the excitability of motor cortex was observed in the functional neuroimaging techniques following the grasping movement phases of the action observed [34].

Significant trapezius muscle activity was not observed in either group, possibly due to the exercises and training involved minimal shoulder range of motion. This is supported by Lam & Bordoni, 2021 where trapezius activity was found to facilitate abduction of the arm from 90 degrees and further upwards [35].

Contribution and participation in therapy is likely to be better when training mimics functional activities. Recovery of arm as evaluated with CMSA showed significant improvement ($p < 0.05$) in RFVE group than conventional group which could be due to games with task that are provided in the virtual environment that depicts tasks of daily living activity motivating them to actively participate in the activity. The results demonstrated that the therapeutic effect of the RFVE training along with conventional training brought a beneficial effect in stroke patients.

People undergoing immersive virtual reality experienced undesirable effects, such as cybersickness, which hampered the learning process, compared to those using non-immersive techniques. [36]. This could be based on the sensory conflict theory, that discrepancies occur between the senses which provide information about the body's orientation and motion leading to a perceptual conflict. However, none of the subjects in the study reported any discomfort during the intervention within the virtual environment. Limitation of the study was its small sample size, as subjects in the acute phase had other complications that prevented them from participating.

Conclusion

The results of this study demonstrate the beneficial effects of RFVE in upper limb training which has shown improvements in muscle activation in SEMG and arm recovery in CMSA scores. VR training is a safe and well-accepted effective intervention in acute stroke rehabilitation that could become a successful intervention for early functional recovery.

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