Johar, M. N., et al., (2025). *J Rehab Pract Res 6*(2): 183
https://doi.org/10.33790/jrpr1100183

Journal of Rehabilitation Practices and Research

Sustained Effectiveness of Game-based Circuit Exercises on Physical Functions and Quality of Life in Stroke Survivors: A Randomized Controlled Trial in Malaysia

Mohd Naqiuddin Johar[1], Nor Azlin Mohd Nordina[2*], Aznida Firzah Abdul Aziz[3]

[1]*Physiotherapy Program, Center for Rehabilitation and Special Needs Studies, Faculty of Health Sciences, Universiti Kebangsaan Malaysia, 50586 Kuala Lumpur, Malaysia.*

[2]*Physiotherapy Unit, Hospital Putrajaya, 92050 Putrajaya, Malaysia.*

[3]*Department of Family Medicine, Faculty of Medicine, Universiti Kebangsaan Malaysia, Cheras, 56000 Kuala Lumpur, Malaysia.*

Article Details

Article Type: Research Article
Received date: 17th March, 2025
Accepted date: 11th September, 2025
Published date: 15th September, 2025

***Corresponding Author:** Nor Azlin Mohd Nordin, Physiotherapy Unit, Faculty of Health Sciences, Universiti Kebangsaan Malaysia, Hospital Putrajaya, 92050 Putrajaya, Malaysia.

Citation: Johar, M. N., Nordina, N. A. M., & Aziz, A. F. A., (2025). Sustained Effectiveness of Game-based Circuit Exercises on Physical Functions and Quality of Life in Stroke Survivors: A Randomized Controlled Trial in Malaysia. *J Rehab Pract Res, 6*(2):183. https://doi.org/10.33790/jrpr1100183

Abstract

Stroke survivors often experience significant functional decline, which affect their quality of life. While circuit exercises improve functional performance, research on incorporating gaming elements in the exercise program remains limited. Game-based circuit exercise using Checkercise®, a newly-introduced gaming board offers a novel approach to stroke rehabilitation by integrating fun into circuit exercise therapy. This study examined its effectiveness compared to conventional circuit exercise in improving lower limb strength, postural stability, aerobic endurance and quality of life. A parallel, randomized controlled trial was conducted among 88 subacute stroke survivors, whom were divided into experimental (Checkercise®) and control (conventional circuit exercise) groups. Both interventions were supervised by physiotherapists, held twice weekly for 12 weeks. The effectiveness of the interventions was measured in term of lower limb strength using 30-second chair rise test, posture stability using Dynamic Gait Index (DGI), aerobic endurance using 6-minute walk test (6mWT) and quality of life using Short Form-36 questionnaire (SF-36). All outcome measures were scored at baseline and post-intervention intervals at 12, 24 and 36 weeks. A blinded assessor conducted the standardized measurements to ensure objectivity and minimize bias. Data analysis was performed using a mixed-model ANOVA to examine differences across time points and assess the interventions' effects. Results showed significant interaction effect ($p<0.05$) with a small effect size (0.03 to 0.04) for the 30-second Chair Rise test and physical and mental scores of SF-36. The experimental group exhibited a 34% greater improvement in chair rise performance compared to 17% in the control group (17%). Similarly, the experimental group showed more substantial increases in SF-36 physical (41%) and mental (29%) component scores than the control group (16% for each). A significant group effect ($p<0.05$) with a small effect size (0.04 to 0.05) was noted for the DGI and 6mWT, where the experimental group outperformed the control group. The experimental group showed an 18% increase in DGI scores, while the control group exhibited a 16% rise. For the 6mWT, scores increased by 30% and 25%, respectively for the experimental and control group. Bonferroni post hoc analyses demonstrated sustained improvements in DGI, 6mWT and the SF-36 physical component score at both three and six months follow-ups within the experimental group ($p<0.05$). The benefits observed in the 30-second Chair Rise test were also maintained at six months. In contrast, improvements in DGI within the control group were sustained only up to three months. In conclusion, stroke survivors experience sustained improvements in physical function and quality of life for up to six months following game-based circuit exercise using Checkercise®. However, the effect of the gaming elements of the intervention warrants further investigations.

Trial registration: Australian New Zealand Clinical Trials Registry, ACTRN 12621001489886 (last updated 1/11/2021)

Abbreviations: Short From-36 = SF-36

Keywords: Stroke, Function, Quality of Life

Introduction

Cerebrovascular accident or stroke, constituted the third leading cause of global mortality in 2021, accounting for approximately 10% of total deaths worldwide [1]. In addition, stroke-related disability is the leading cause of disability worldwide [2]. In 2019, stroke imposed a substantial global burden, evidenced by approximately 12.2 million new cases, a prevalence of 101 million and 143 million disability-adjusted life-years (DALYs) [3]. Advancements in medical care have contributed to a general decline in acute stroke mortality rates. As a result, many countries are observing a growing population of stroke survivors living with disabilities resulting from their stroke [4]. Elevated rates of stroke-related disability, demanding continuous and long-term rehabilitative and medical support, represent a significant challenge to healthcare systems, particularly in low-resource settings [5].

Rehabilitation is central to post-stroke care, with a specific focus on minimizing impairments, reducing disability and enhancing functional independence among the survivors. Physiotherapy, a key component of multidisciplinary rehabilitation, is crucial across all post-stroke recovery phases. Physiotherapeutic interventions commonly utilized for post-stroke individuals comprise diverse categories, such as therapeutic and functional exercise regimens, electrophysical modalities for analgesia or neuromuscular activation, manual therapy techniques and contemporary approaches including virtual reality, mirror and robotic therapies as well as specialized methods like motor relearning and the Bobath approach [6]. In many countries, post-stroke rehabilitation services are initiated during hospitalization for the acute and subacute phases of stroke and are commonly continued in outpatient facilities upon the patient's discharge to their residence.

Therapeutic exercise, with an emphasis on task-specific training, frequently recommended as a primary physiotherapy intervention for stroke rehabilitation [7-10]. It can be administered in either individual or group sessions. Group sessions are typically structured as circuit class exercises. A circuit class session involves a group of three or more participants practising a range of tasks repetitively at workstations within visual proximity of one another, under the supervision of two to three physiotherapists [11]. The workstations consist of a variety of mobility, strength training and aerobic exercises; each workstation lasts for about 5 to 10 minutes depending on the number of stations (usually between 4 to 10 stations) to be completed, with 2 to 3 minutes rest intervals. Circuit exercise for post-stroke individuals is typically administered at a frequency of one to three sessions per week and may be continued for a duration of one month or more, and tailored to the individual stroke survivor's needs [12-15]. Although it is normally organized for a group of participants, this exercise training can be conducted for a single participant. Studies of circuit exercise documented that the intervention assists in further improving stroke survivors' functionality and quality of life [16-17].

Therapeutic exercise which integrates gaming is a popular physiotherapy intervention for stroke survivors in recent times. The actions to be performed by stroke survivors in game-integrated therapeutic exercise resemble gaming actions in sports such as soccer, boxing, athletics, and others. The game-integrated exercises can be delivered either through usual exercise training, robotic-assisted training [18-20] or virtual reality-based therapy [21-24]; with the individual session potentially conducted as a home-based exercise program [25]. Despite the expanding utilization of game-integrated exercises across various demographics, a notable gap persists concerning games specifically designed to address the needs of stroke survivors. In addition to ensuring personalized motivation and creating fun among stroke survivors during exercise therapy, training within an enriched environment, employing multisensory cueing, limb integration and cognitive stimulation are essential for promoting neuroplasticity and enhancing functional recovery. Combining game-integrated exercise with circuit exercise would be an excellent strategy for post-stroke rehabilitation [26]. Nonetheless, to the best of our knowledge, no studies have integrated design-for-fun game environments within established circuit exercise training protocols.

Therefore, this study was intended to evaluate the comparative effectiveness of game-based versus conventional circuit exercises on functional outcomes and quality of life in stroke survivors. Furthermore, the study determined the sustainability of intervention-related improvements up to six months post-intervention.

Methods

Study design and setting

The present study employed an assessor-blinded randomized controlled trial (RCT) design, and was executed at Hospital Putrajaya, a principal stroke referral facility situated in Putrajaya, the federal administrative capital of Malaysia. Ethical approval for the RCT was granted by the National Medical Ethics and Research Committee (NMERC), Malaysian Ministry of Health (study ID: NMRR–20–2715–57464), in compliance with the Declaration of Helsinki. The protocol was also registered with the Australian New Zealand Clinical Trials Registry on November 1, 2021 (ACTRN 12621001489886). The protocol details of this study have been published elsewhere [27].

Study participants

Participants' recruitment occurred between June 2021 and March 2023. A total of 96 stroke survivors, comprising 38 individuals with ischemic stroke and 58 with infarct stroke, with a mean age of 57.1 ± 10.8 years and a mean body mass index of 25.8 ± 5.4 kg/m², whom referred for physiotherapy at the identified hospital were initially screened. The required sample size for this study was calculated using G*power software version 3.1 for ANOVA repeated measures, within-between interactions. Targeting a statistical study power of 80% and an alpha level of 0.05, a minimum sample of 82 participants, 41 per trial group, was required. Following eligibility screening, 88 participants were suitable and thus, 44 participants for each of the experimental and control groups were recruited.

Participants' inclusion criteria were,

1. clinically diagnosed hemorrhagic or ischemic stroke, confirmed by a physician,
2. age range between 40 to 80 years,
3. exhibits basic functional mobility including ambulation and stair negotiation with or without a walking aid and unilateral upper extremity manipulation of a full glass of water.

Excluded were stroke survivors with,

1. a score of 22.1 or below on the Montreal Cognitive Assessment (MoCA), indicating cognitive impairment,
2. medical conditions such as severe musculoskeletal disorders, unstable angina or uncontrolled hypertension that would significantly limit physical functionality,
3. chronic central nervous system pathology other than stroke such as Parkinson's disease and polyneuropathy,
4. Modified Rankin Scale (mRS) score of 4 or higher, indicating moderate-severe to severe disability,
5. participation in home-based physiotherapy or received traditional therapeutics services following discharge from an inpatient setting,
6. visual field defects.

Group allocation and blinding

Recruited participants were randomized into either the experimental group or the control group using stratified block randomization method after obtaining an informed consent and baseline measurements using 1:1 allocation ratio. Stratification variables were age (middle aged adult: 55 to 59 years; older adult: 60 to75 years) and disability level (Modified Rankin Scale score of 2 or less; Modified Rankin Scale score of 3). An independent researcher performed the randomization and concealed, allocation using the sealed opaque envelope approach. The implementation of the study which involved patient enrolment and administration of the intervention were done by a trained therapist. Another trained therapist, external to the study and blinded to the group allocation conducted the baseline and post intervention assessment. All participants were provided with unique identification number to ensure anonymity.

Interventions

The experimental group received game-based circuit exercises using a gaming board named Checkercise®, which features a design replicating the 'snake and ladder' game. The exercise protocol, adhering to the frequency, intensity, time and type (FITT) principle, is summarized in Table 1.

Formula	Resistance exercise	Balance exercise	Aerobic exercise
Frequency	Repeated sit to stand	Walking on balance beam	Alternate jab
	2 sessions/week	2 sessions/week	2 sessions/week
Intensity	Speed at 50 beats per minute	Speed at 30 beats per minute	Speed at 100 beats per minute
Time	1 minute	1 minute	1 minute
Technique	Alternate seated to standing (without load)	Walking on balance beam (follow rhythm)	Repeated jab punching (follow rhythm)
Progression	Alternate seated to standing (Lifting up 2 kg of dumbbell)	Tandem walking (follow rhythm)	Repeated double jab punching with defense (follow rhythm)
Frequency	Repeated partial squat	Figure of 8 walking	Alternate hook
	2 sessions/week	2 sessions/week	2 sessions/week
Intensity	Speed at 30 beats per minute	Speed at 45 beats per minute	Speed at 100 beats per minute
Time	1 minute	1 minute	1 minute
Technique	Standing, partial squats with arm support as needed (without load)	Figure of 8 walking (follow rhythm)	Repeated hook punching (follow rhythm)
Progression	Standing, partial squats with arm support as needed (Lifting up 2 kg of dumbell/ speed at 50 beats per minute)	Figure of 8 walking while holding cup of water	Repeated alternate hook with kicking (follow rhythm)
Frequency	Repeated step up & down	Walking with instruction	Double jab & hook
	2 sessions/week	2 sessions/week	2 sessions/week
Intensity	Speed at 70 beats per minute	-	Speed at 100 beats per minute
Time	1 minute	1 minute	1 minute
Technique	Standing, alternate steps-ups on the 8-inches step (without load)	Walking & stop (closed eyes in static standing)	Repeated double jab punching with hook (follow rhythm)
Progression	Standing, alternate steps-ups on the 8 inches step board (Lifting up 2 kg of dumbbell/speed at 75 beats per minute)	Walking while sudden change instruction	Repeated double jab punching with hook & squat (follow rhythm)
Frequency	Standing; repeated hip raise	Walk and touch cones	Double jab
	2 sessions/week	2 sessions/week	2 sessions/week
Intensity	Speed at 45 beats per minute	Speed at 20 beats per minute	Speed at 100 beats per minute
Time	1 minute	1 minute	1 minute
Technique	Standing, alternate steps-ups on the 8-inches step board (without load)	Walk & touch cones cuboid shape (follow rhythm)	Repeated double jab punching with defense and kick (follow rhythm)
Progression	Standing, alternate steps-ups on the 8-inches step board (Lifting up 2 kg of dumbbell/speed at 50 beats per minute)	Walk & touch cones hexagon shape (follow rhythm)	Repeated double jab punching with squat (follow rhythm)
Frequency	Standing; repeated heel raise	Backward walking	Cross straight
	2 sessions/week	2 sessions/week	2 sessions/week
Intensity	Speed at 70 beats per minute	Speed at 45 beats per minute	Speed at 100 beats per minute
Time	1 minute	1 minute	1 minute
Technique	Standing, alternate raises heel (without load)	Backward walking (follow rhythm)	Repeated cross straight punching (follow rhythm)
Progression	Standing, alternate raises heel (Lifting up 2 kg of dumbbell/speed at 75 beats per minute)	Backward walking (follow rhythm for 2 minutes)	Repeated 4 times cross straight punching with squat (follow rhythm)

Table 1: Description of the of the Checkercise® board exercises

Participants commence by positioning their counter on the space designated "start." Following this, participants take turns to roll a dice. The numerical value displayed on the dice dictates the subsequent forward movement of their counter across the game board. The exercise assigned to each participant is contingent upon the specific space their counter occupies after each dice rolled. Each space on the board corresponds to a unique exercise task. Furthermore, designated "penalty or reward spaces" are incorporated, examples of such spaces include instructions to regress a specified number of spaces or advance to a predetermined board position. The completion of the game-based circuit exercise is defined by each participant's arrival at the space designated "finish" with the first participant to do so identified as the winner.

Checkercise® is designed for implementation in group sessions comprising four participants. To incorporate fun elements, Checkercise® was delivered through competitive challenges. These features, embedded within the gameplay, were designed to enhance participants' motivation and enjoyment during the intervention.

In general, the Checkercise® board introduces a novel integration of resistance, balance and aerobic exercises within a gamified framework. Resistance exercises emphasize inter-limb coordination through tasks such as dumbbell lifting during seated-to-standing transitions, squats with step-ups and step-downs, and hip and heel raises. Balance exercises involve dual-task dynamic movements and visual cueing, including walking to touch cones, walking with head turns and navigating figure-of-eight patterns while carrying a partially filled cup, all performed concurrently with cognitive challenges. Aerobic exercises comprise progressive boxing sequences, ranging from basic punches (jab, hook, cross-straight) to complex combinations involving coordinated upper and lower limb movements, such as hook with kick, jab with squat and cross-straight with squat. Metronome beats were incorporated throughout the Checkercise® exercise program to enhance participants' attentional focus during task execution. Exercise difficulty is systematically adjusted by modifying speed and load to accommodate individual participant abilities. The integration of inter-limb coordination, dual--task dynamic movements, visual cueing, boxing maneuvers and auditory stimuli in this study contributed to a more enriched and stimulating rehabilitation environment [28].

Each exercise bout within the protocol is standardized to a duration of two minutes, followed by a two-minute rest interval. The complete Checkercise® protocol encompasses an average of ten distinct exercises, with an anticipated total session duration averaging 40 minutes. Throughout a 12-week intervention period, participants engaged in the Checkercise® protocol twice weekly at a self-selected pace under the direct supervision of the primary researcher. To ensure protocol fidelity and evaluate exercise intensity, session attendance was systematically documented using attendance checklists and the perceived exertion levels for each session were assessed using the Borg Rating of Perceived Exertion scale, respectively.

Meanwhile for the control group, two physiotherapists supervised participants in performing conventional circuit exercises. Each session was structured to accommodate five participants, rotating systematically through six designated exercise stations. These stations were comprised of: 1) cycling, 2) repeated sit-to-stand exercises, 3) repeated arm curl exercises, 4) repeated hip and heel raise exercises, 5) step-up exercises and 6) obstacle walking. Exercise duration at each station was set at five minutes, followed by a two-minute inter--station rest period. The perceived exertion levels for each participant in each station was assessed using the Borg Rating of Perceived Exertion scale. Consistent with the experimental group protocol, the control group also undertook 40-minute sessions, administered twice weekly over a 12-week period.

Outcome assessments

To determine the interventions effectiveness, the following outcome variables and standardized measures were employed:

- Lower limb strength was assessed using the 30-second chair stand test. In this test, participants were instructed to repeatedly rise to a full standing position from a standardized chair, 42 cm in height and 47.5 cm in depth, with arms crossed across the chest within a 30-second period. Normative values for this test, indicative of typical performance in healthy individuals aged 55 to 75 years, are reported to range from 14 to 17 repetitions for males and 13 to 15 repetitions for females [29]. The 30-second chair stand test has high test-retest reliability (Intraclass Correlation Coefficient [ICC] = 0.89) and a moderate correlation with the leg press test in individuals post-stroke (correlation coefficient [r] = 0.77) [29].
- Dynamic balance during ambulation was evaluated using the Dynamic Gait Index (DGI). Normative data for the DGI in healthy individuals aged 50 to 79 years indicate a mean score range of 23.2 ± 0.9 to 23.9 ± 0.4 [26]. Participants completed all eight tasks comprising the DGI, which included: 1) Walking on a level surface, 2) Walking with changes in gait speed, 3) Walking with horizontal head turns, 4) Walking with vertical head turns, 5) Walking with a pivot turn, 6) Stepping over obstacles, 7) Stepping around obstacles, and 8) Stair climbing. Each task is scored on a 4-point ordinal scale ranging from 0 (indicating severe impairment) to 3 (representing normal performance). The DGI has demonstrated high test-retest reliability (ICC = 0.94 to 0.96) [30, 31]. Total DGI scores range from 0 to 24, with higher scores indicative of greater independence in functional mobility among individuals post-stroke.
- A 6-minute walk test (6mWT) measured aerobic endurance by recording the distance participants walked over six minutes along a ten meters course. Normative data for the 6-Minute Walk Test (6mWT) in healthy individuals aged 50 to 79 years indicate a walked distance ranging from 357 to 697 meters for males and from 321 to 621 meters for females [32]. It is also reported that higher normative values, ranging from 421 to 795 meters for males and 392 to 765 meters for females within the same age group, have been observed [33]. The 6mWT demonstrated high test-retest reliability (ICC = 0.99) [34-35].
- Quality of life (QoL) was assessed using the Short Form-36 (SF-36) questionnaire, which evaluates participants' QoL across eight domains (36 questions) which covered: 1) physical health component, which includes physical functioning (ten questions), role limitations due to physical health (four questions) and pain (two questions); 2) mental health component, which includes social functioning (two questions), role limitations due to mental health issues (three questions) and emotional wellbeing (five questions) and 3) physical and mental health component, which includes general health (five questions) and energy/fatigue (four questions). The SF-36 has demonstrated moderate to high test-retest reliability in post-stroke individuals, with ICC ranging from 0.57 to 0.8 [36-38]. Total scores on the SF-36 range from 0 to 100, with higher scores indicative of a better quality of life.

All outcome assessments were conducted by a one therapist who was blinded to the group allocation and trained in the tests administration. Measurements were performed at baseline, post-intervention (12 weeks) and at 12 and 24-week follow-up intervals. To mitigate assessor bias, baseline data were withheld from the assessor during post-intervention and follow-up assessments. No specific exercise prescription was provided to participants in either group following the 12 week intervention; they were directed to continue their usual daily activities until assessed at follow-up sessions.

Data analysis

A mixed model ANOVA was used to analyze the effects of time, group and their interaction on the outcome variables. F-tests within the repeated measures framework of ANOVA were conducted to assess these effects. Assumptions of normality (Shapiro-Wilk) and homogeneity of variance (Fmax and Levene's) were tested and met. The significance level was set at $p<0.05$.

An intention-to-treat (ITT) analysis was conducted, including all randomized participants in outcome assessments, regardless of protocol adherence. Missing data were imputed using the last observation carried forward (LOCF) method to mitigate bias from attrition. Cohen (2013) [39] has provided benchmarks to define small ($\eta^2 = 0.01$), medium ($\eta^2 = 0.06$), and large ($\eta^2 = 0.14$) effects.

Results

Participant flow across all study phases is detailed in the CONSORT diagram (Figure 2). The game-based circuit exercise group included 44 participants (mean age = 58.6 ± 9.9 years), while the conventional circuit exercise group also consisted of 44 participants (mean age = 55.5 ± 11.4 years). Within the experimental group, two participants withdrew from the intervention, citing an inability to continue participation, while one participant per group was lost to follow-up.

Table 2 shows the socio-demography and baseline basic clinical data for the study participants. Majority of the participants were male (75% in game-based circuit exercises and 64% in conventional circuit exercises). Both groups presented with overweight status (more than 25 kg/m² of body mass indexes) and mild disability (scores of mRS 2 or less). The mean time post-stroke was similar between groups (7.3 weeks in experimental group and 7.5 weeks in control group).

Tables 3 and 4 provide the descriptive and statistical indices for physical functions (30-second chair rise test, DGI and 6mWT) and QoL (SF-36) outcomes. A 2 × 4 mixed-model ANOVA was performed to compare the effects of game-based versus conventional circuit exercise on these outcomes in stroke survivors.

For the 30-second chair rise test, a significant interaction effect was demonstrated ($p<0.05$) ($p = 0.01$, small effect size of $\eta^2 = 0.04$). A significant interaction ($p<0.05$) was also found for the SF-36 physical component ($p = 0.001$, small effect size of $\eta^2 = 0.01$) and SF-36 mental component ($p = 0.05$, small effect size of $\eta^2 = 0.03$). In addition to interaction effects, significant group effects were observed for both DGI ($p = 0.039$, small effect size of $\eta^2 = 0.05$) and 6mWT ($p = 0.05$, small effect size of $\eta^2 = 0.04$). Participants in the experimental group achieved higher DGI scores and longer 6mWT distances compared to the control group ($p<0.05$). Whereas, significant main effects of time ($p<0.001$) were found for all outcome measures. These time effects were large for all measures, as follows: 30-second chair rise test ($\eta^2 = 0.28$), DGI ($\eta^2 = 0.45$), 6mWT ($\eta^2 = 0.39$), SF-36 physical component ($\eta^2 = 0.33$) and SF-36 mental component ($\eta^2 = 0.26$).

Bonferroni post hoc analyses (Table 5) demonstrated that beneficial effects on 6mWT and SF-36 physical component performance were maintained in the experimental group at 3- and 6-month follow-up ($p<0.05$). The benefits observed in the 30- second chair rise test were also maintained at six months. In contrast, improvements in DGI within the control group were sustained only up to three months.

Figure 1: Design of the Checkercise® board

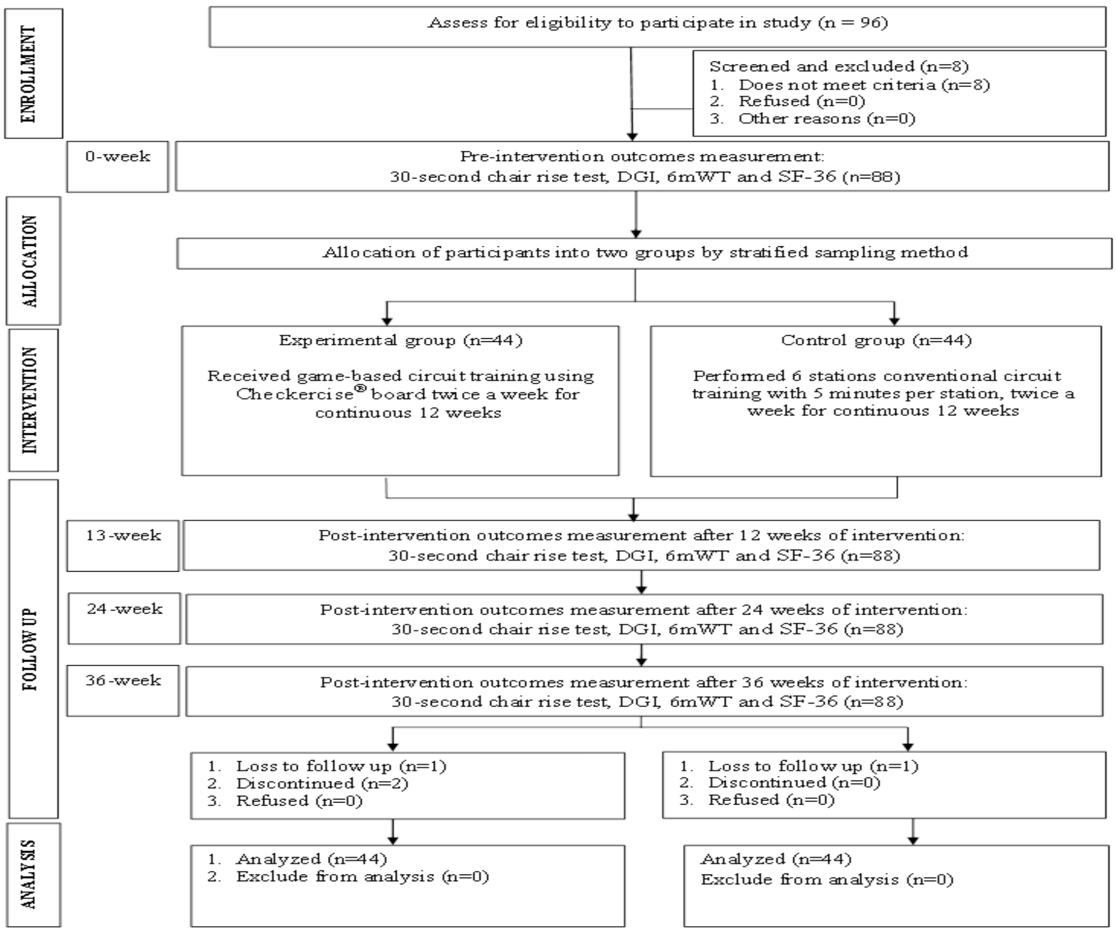

Figure 2: CONSORT diagram of the study

Variables	Experimental group (n=44)	Control group (n=44)	p-value
Age (years)	58.61 + 9.91	55.48 + 11.42	0.173
Gender (Female)	25%	36%	0.248
Cognitive, MOCA	26.43 + 3.32	26.34 + 3.57	0.902
Type of stroke (Ischemic)	25%	30%	0.632
mRS (Moderate disability)	18.18%	22.73%	0.062
Side of hemiparesis (Right)	50%	50%	1.0
Side of dominance (Right)	95%	100%	1.0
Body mass index (kg/m²)	26.67 + 6.1	24.93 + 4.61	0.135
Post-stroke duration (weeks)	7.3	7.5	0.182
30-second chair rise test	9.41 + 3.24	10.41 + 3.93	0.197
DGI	18.8 + 4.26	17.32 + 4.9	0.135
6mWT	268.45 + 74.53	235.59 + 121.45	0.130
SF-36			
Overall physical component	50.71 + 12.48	53.44 + 15.1	0.358
Physical function	58.07 + 17.02	58.98 + 21.34	0.826
Role limitation physical	15.53 + 24.35	18.37 + 31.67	0.638
Pain	66.31 + 22.58	71.76 + 22.78	0.263
General health	62.96 + 19.15	64.66 + 16.3	0.654
Overall mental component	59.73 + 20.58	61.73 + 20.0	0.645
Role limitation emotional	35.22 + 36.7	34.85 + 43.11	0.965
Energy /fatigue	62 + 18.18	64.66 + 18.72	0.499
Emotional well being	70.68 + 19.15	71.91 + 16.36	0.747
Social functioning	71.02 + 26.79	75.51 + 24.82	0.417

Table 2: Baseline for social demographic data and characteristics of participants

All data are presented as mean ± standard deviation with a *p*-value for Independent T-test, except for ethnicity, gender, type of stroke, mRS (modified Rankin Scale), side of hemiparesis are demonstrated in number of participants (%) with a p-value for Chi-squared test. Statistically significant, **p*<0.05. MOCA, Montreal Cognitive Assessment; 30-second chair rise test, DGI, Dynamic Gait Index; 6mWT, 6-minute walk test; and SF-36, Short Form-36 questionnaire.

Measures	Experimental group (n=44)					Control group (n=44)				p-value			
	0-week	12-week	24-week (3-month follow up)	36-week (6-month follow up)	Cha-nges	0-week	12-week	24-week (3-month follow up)	36-week (6-month follow up)	Cha-nges	Time effect	Group effect	Interaction effect
30-second chair rise test	9.41 + 3.24	11.39 + 3.83	12.2 + 3.68	12.64 + 3.51	34%	10.41 + 3.93	11.7 + 3.75	11.59 + 3.57	12.2 + 4.06	17%	*0.001 (#0.28)	0.925	*0.01 (#0.04)
DGI	18.8 + 4.26	21.25 + 3.9	21.9 + 4.02	22.09 + 3.99	18%	17.4 + 4.93	19.26 + 4.6	19.9 + 4.45	20.12 + 4.28	16%	*0.001 (#0.45)	*0.039 (#0.05)	0.458
6mWT	268.45 + 74.53	309.34 + 87.94	338.2 + 96.57	348.82 + 98.49	30%	235.59 + 121.5	276.6 + 118.33	287.61 + 121.01	294.34 + 123.84	25%	*0.001 (#0.39)	*0.05 (#0.04)	0.131

Table 3: Comparison of changes in leg strength, posture stability and aerobic endurance between the two groups at baseline and week 12, 24, 36 after intervention

Measures	Experimental group (n=44)					Control group (n=44)				p-value			
	0-week	12-week	24-week (3-month follow up)	36-week (6-month follow up)	Cha nges	0-week	12-week	24-week (3-month follow up)	36-week (6-month follow up)	Cha nges	Time effect	Group effect	Interaction effect
Overall physical component	50.71 + 12.48	65.5 + 15.81	70.43 + 17.88	71.34 + 18.83	41%	53.44 + 15.1	58.45 + 20.02	61.84 + 19.67	62.22 + 18.7	16%	*0.001 (#0.33)	0.095	*0.001 (0.007)
Physical function	58.07 + 17.02	76.14 + 13.59	77.84 + 16.26	78.87 + 17.35	36%	58.98 + 21.34	65.46 + 21.94	70.46 + 18.52	71.02 + 19.25	20%	*0.001 (#0.31)	0.06	*0.007 (0.05)
Role limitation physical	15.53 + 24.35	35.98 + 37.47	51.33 + 40.58	55.3 + 41.5	256%	18.37 + 31.67	31.25 + 40.03	37.69 + 42.93	38.83 + 40.47	111%	*0.001 (#0.23)	0.223	*0.054 (0.03)
Pain	66.31 + 22.58	77.27 + 20.32	79.03 + 20.13	76.76 + 21.68	16%	71.76 + 22.78	68.92 + 24.31	70 + 25.06	71.53 + 23.67	0.3%	*0.015 (#0.04)	0.314	*0.001 (0.07)
General health	62.96 + 19.15	72.61 + 21.42	73.52 + 20.36	74.43 + 20.12	18%	64.66 + 16.3	68.18 + 18.24	69.21 + 18.86	67.5 + 20.31	4%	*0.001 (#0.13)	0.354	*0.021 (0.04)
Overall mental component	59.73 + 20.58	72.66 + 19.64	75.46 + 19.27	77.12 + 18.97	29%	61.73 + 20.0	67.41 + 21.41	70.73 + 21.22	71.56 + 20.6	16%	*0.001 (#0.26)	0.382	*0.052 (0.03)
Role limitation emotional	35.22 + 36.7	60.61 + 40.21	66.66 + 39.38	68.18 + 38.69	94%	34.85 + 43.11	50 + 44.61	56.06 + 44.77	59.85 + 41.04	72%	*0.001 (#0.22)	0.318	0.484
Energy / fatigue	62 + 18.18	71.71 + 18.49	71.96 + 17.73	74.46 + 17.63	20%	64.66 + 18.72	64.55 + 20.43	66.59 + 20.74	66.93 + 21.95	3%	*0.001 (#0.11)	0.247	*0.001
Emotional well being	70.68 + 19.15	79.82 + 16.68	80.55 + 15.18	82.05 + 15.43	16%	71.91 + 16.36	75.82 + 18.01	76.46 + 18.02	75.64 + 18.6	5%	*0.001 (#0.15)	0.32	(0.06)
Social functioning	71.02 + 26.79	78.52 + 22.28	82.67 + 21.6	83.81 + 19.92	18%	75.51 + 24.82	79.26 + 21.22	83.81 + 20.46	83.81 + 20.63	11%	*0.001 (#0.11)	0.691	*0.025

Table 4: Comparison of changes in quality of life between the two groups at baseline, week 12, 24, 36 after intervention

Values are presented as mean ± standard deviation; η^2, partial eta squared; statistically significant, *p < 0.05 by Mixed Model ANOVA; DGI, Dynamic Gait Index; 6mWT, 6-minute walk test; and SF-36, Short Form-36 questionnaire.

Measures	Experimental group (n=44)		Control group (n=44)	
	13-week to 24-week (3-month follow up)	13-week to 36-week (6-month follow up)	13-week to 24-week (3-month follow up)	13-week to 36-week (6-month follow up)
30-second chair rise test	0.071	*0.004	1	0.463
DGI	*0.001	*0.001	*0.013	*0.005
6mWT	*0.001	*0.001	0.382	0.126
Overall SF-36 physical component	*0.030	*0.017	0.284	0.241
Overall SF-36 mental component	0.393	0.108	0.362	0.157

Table 5: Bonferroni post hoc analysis between post intervention (week-13), 24-week (3-month follow up) and 36-week (6-month follow up) measurement in all outcomes in both groups

Values were presented as statistically significant, *$p < 0.05$ by Mixed Model ANOVA pairwise comparisons; DGI, Dynamic Gait Index; 6mWT, 6-minute walk test; and SF-36, Short Form-36 questionnaire.

Discussions

The purpose of this study was to evaluate and compare the effects of game-based versus conventional circuit exercise on physical functionality, namely lower limb strength, postural stability and aerobic endurance and QoL in individuals post-stroke.

Interaction effect

A significant interaction effect on leg strength was observed. Following the 3-month intervention, leg strength in the experimental group was doubled compared to the control group participants. These results corroborate previous research [40-41]. Eichinger et al. (2020) [40] investigated whether serious game training (exercise-based paretic lower limb rehabilitation using SG mim-Pong, with game parameters configured for racket size, ball size and ball speed) was beneficial for 24 stroke survivors' lower limb strength as compared to conventional exercise (passive mobilization techniques, stretching exercises and active-assisted movement therapy). Another study was conducted by Kim and Lee (2012) [41] compared the effect of the combination of augmented reality on a treadmill exercise with functional electrical stimulation, treadmill exercise with functional electrical stimulation and functional electrical stimulation alone. Both studies concluded that game-based intervention has significant results in improving quadriceps femoris and hamstrings, measured using dynamometer in stroke [40-41].

The improvement of lower limb strength gained following the Checkercise® program can be associated with inter-limb coordination. Inter-limb coordination, the coordinated motion of four limbs for task completion, is theorized to improve limb control by enhancing neural coupling between arms and legs [42]. An example of inter-limb coordination demonstrated during Checkercise® gameplay includes tasks such as dumbbell lifting during seated-to-standing transitions, performing squats followed by standing step-ups and step-downs, as well as executing hip raises and heel raises.

Demanding coordinated, alternate exercise such as rowing and elliptical machine training provide further evidence to highlight the significance of upper and lower limb coordination for lower limb strength [43-44]. A recent randomized controlled pilot trial assessed the effectiveness of computerized rowing exercise as compared to the usual resistance exercise routine in 38 older individuals with knee osteoarthritis [43]. The 12-week intervention of an experimental group comprised of inter-limb coordinated tasks with the use of a computer-aided rowing exercise. Compared to the control group after the intervention, the experimental group demonstrated significantly higher adjusted mean post-test scores. Specifically, significant mean differences favoring the experimental group were found for hip and knee muscle strength. Another study, a case report by Oza [44] has concluded that elliptical training of 3 sessions per week for 4-week has significant results in improving lower limb strength through Voluntary Control Grading. Repeated motions in elliptical and rowing machine training have improved motor learning and participants' functional activity in daily living, measured using Tinetti Performance Oriented Mobility Assessment and Western Ontario and MacMaster Universities, respectively [43-44].

Following a three-month intervention, participants in the experimental group exhibited a statistically significant improvement in their quality of life, encompassing both physical and mental health components. This enhancement represented a twofold increase when compared to the control group. This findings was in line with the previous studies conducted by de Rooijet al. (2021) [45] and Akinci et al. (2024) [46] which showed that virtual reality training with the Gait Real-Time Analysis Interactive Lab (GRAIL) and robot-assisted gait training with virtual reality both resulted in statistically significant and comparable improvements in quality of life through Stroke Specific Quality of Life, contrasting with conventional therapy alone. These findings were derived from cohorts undergoing GRAIL and robot-assisted virtual reality interventions. While de Rooijet al. (2021) [45] and Akinci et al. (2024) [46] reported that game elements and variations in virtual reality gaming environments enhanced the quality of life in individuals with sub-acute stroke, our findings demonstrate that the Checkercise® gameplay, featuring mechanisms such as dice rolling, rewards, and penalties, effectively improved both the physical and mental components of quality of life in a comparable population. Furthermore, participants reported positive responses toward the game-based elements and environmental enrichment, which contributed to a more enjoyable training experience and facilitated implicit motivation.

A plausible explanation for this finding lies in the daily living requirement of executing a complex sequence of dual-task dynamic movements in the Checkercise® gameplay such as walk and touch cones, walking with head turns and figure-of-eight trajectories while carrying a partially filled cup of water. Dual motor tasks were performed concurrently with cognitive stimulation designed to enhance task interactive, a game like situation would make doing these exercises more fun and less boring. Cognitive tasks involved serial naming such as countries alphabetically (A-Z) and animals reverse alphabetically (Z-A). These tasks necessitate diverse kinematic patterns and motor control strategies in daily living. Pang et al. (2018) [47] demonstrated that dual-task performance significantly enhanced relative to single-task performance among 84 individuals with a mean age of 61 years. Specifically, stroke survivors in dual-task balance and mobility training exhibited improved outcomes during walking tasks performed concurrently with cognitive challenges

JRPR, an open access journal
ISSN 2581-3846

such as verbal fluency and serial subtractions of 3 during walking time, and the timed up and go test. In addition, dual-task training, employing either variable or fixed priority instructional sets demonstrated significant improvements in 41 chronic stroke survivors across several measures, including the Modified Motor Assessment Scale, Berg Balance Scale, gait speed and 6mWT in another study [48]. Quality of life improvements were measured using the Stroke-specific Quality of Life Scale [47] and the EuroQol 5-dimensions [48] in the experimental group were sustained at 4 to 6 months follow-up [47-48].

Between-group difference (group effect)

The study demonstrates a significant group effect on postural stability, where the experimental group demonstrated a statistically significant improvement in performance compared to the control group. Quantitatively, DGI scores in the experimental group increased by 18%, while the control group exhibited an increase of 16%. Consistent with these findings, a prior investigation by Lee et al. (2016) [49] reported comparable positive outcomes in a small study involving 10 patients, suggesting the potential efficacy of virtual reality training in promoting similar enhancements. The study also demonstrated that virtual reality training, incorporating the Nintendo Wii Sports-canoeing game, alongside physiotherapy, occupational therapy and functional electrical stimulation, led to significant gains in postural stability evaluated using the Berg Balance Scale and Timed Up and Go test among stroke survivors compared to a control group. Another study by Anwar et al. (2022) [50] have demonstrated virtual reality training, including Nintendo Wii Sports games improved Berg Balance Scale scores in 74 stroke survivors. Furthermore, they reported that virtual reality training was significantly more effective than conventional treatment, defined as stretching and strengthening exercises for improving upper limb function, measured using the Fugl-Meyer Upper Extremity Assessment. Tennis, boxing and canoeing games from Nintendo Wii Sports were employed in both studies as the mode of game-based virtual reality training [49-50].

The augmented Checkercise® program incorporating visual cueing through colorful cone and floor mat in the most balance training component of Checkercise® during walking with instruction, figure of 8 walking and touching cones while walking; may have positively impacted participants' postural stability. Visual cueing, when added to walking training demonstrated a significant enhancement in Berg Balance Scale and Timed Up and Go test performance among stroke survivors [51-53]. Hollands et al. (2015) [51] highlighted the effectiveness of both over-ground and treadmill based with visual cue training in boosting postural stability including turning in 56 stroke survivors with mean age 59 years. While Shin & Chung (2022) [53] study findings indicated that integrating visual feedback and rhythmic auditory cueing into treadmill training effectively enhanced postural stability in a group of 32 patients. The studies also showed significant results in improving spatiotemporal parameters of gait especially in speed, stride length, cadence and variability [51-53].

This study reveals a significant group effect on aerobic endurance, with the experimental group displaying consistently higher levels of performance relative to the control group. Notably, the 6mWT scores demonstrated increases of 30% and 25%, respectively. These findings are consistent with and support the findings of several prior researches, Fahmy et al. (2024) [54] reported that virtual reality training, incorporating Nintendo Wii Fit Plus aerobic activities games, enhanced the efficacy of conventional therapy in improving aerobic endurance, as evaluated by the 6MWT compared to conventional therapy alone. Another study conducted by Akinci et al. (2023) [55] reported that three virtual reality Lokomat games, namely Faster (for endurance), Gbarello-Smile (for attention and motivation) and Curve pursuit-Treasures-High flyer (for activity timing) which incorporated into robot-assisted gait training improved aerobic endurance significantly, measured using 6mWT when compared to conventional therapy alone. While spatiotemporal gait analysis was performed across both studies [54-55], a significant increase in paretic step length was evident solely after the combined approach of Nintendo Wii Fit Plus aerobic games and conventional therapy [54].

One of the uniqueness of the game-based circuit exercise using Checkercise® board lies in its integration of boxing maneuvers to target various fitness components. Boxing movements involve a complex sequence, ranging from basic punching techniques such as the jab, hook, and cross-straight, to more demanding tasks that require coordinated upper and lower limb movements. These include actions like hooking with a kick, jab with a squat, and cross-straight with a squat. The difficulty of these boxing exercises is systematically adjusted by modifying the speed and load to align with the participants' individual abilities. Exercise intensity is further optimized by progressively increasing the complexity of tasks and the tempo of the metronome beeps. In a systematic review, Sánchez-Lastra et al. (2020) [56] examined the therapeutic applications of boxing as a rehabilitation strategy across 138 individuals with diverse health conditions. Out of 10 studies selected for the review, 3 experimental studies assessed the impact of boxing as a rehabilitation approach for stroke survivors. Among these 3 studies, 2 documented variations in heart rate and energy expenditure during virtual reality boxing exercises in stroke survivors [57-58]. For stroke survivors, energy expenditure varied between 1.81±0.7 METs during Wii™ sitting boxing and 3.46±1.3 METs during Wii™ standing boxing. Exercise intensity for this group ranged from 49.8 ± 9.3% to 64.7 ± 9.3% of their predicted maximal heart rate. Conversely, both energy expenditure and exercise intensity were significantly lower in comparison to able-bodied participants [53]. Wii™ boxing has been classified as a hard-intensity activity, with a METs ranging from 3.46 to 4.1 [57-58]. The classification adheres to the six standard activity intensity categories for post-stroke survivors, namely sedentary (1.5 METs or lower), very light (1.51 to 1.79 METs), light (1.80 to 2.59 METs), moderate (2.60 to 3.39 METs), hard (3.40–4.39 METs) and very hard (4.40 METs or higher) [59].

Within-group difference (time effect)

Study outcomes revealed a significant effect of time across all outcome variables. Notably, both the experimental and control groups demonstrated improvements in lower limb strength, postural stability, aerobic endurance and quality of life. The primary objective of the conventional circuit training regimen employed in the control group is to emphasize diverse patterns and enhance the quality of task-oriented training, particularly focusing on sit-to-stand movements, step-up-and-down exercises and heel raises. These components align closely with the findings of our study.

Previous research has demonstrated that sit-to-stand training significantly enhances lower limb strength in stroke survivors [60-62]. For instance, Tung et al. (2010) [62] reported that the inclusion of 15 to 30 minutes of sit-to-stand training alongside general exercise regimens improved lower limb extensor strength, assessed via hand-held dynamometry, among a cohort of 32 stroke survivors. Similarly, de Sousa et al. (2019) [61] found significant improvements in lower limb extensor strength when measured using an inclinometer among 30 stroke survivors. Amala and Chippala (2024) [60] further highlighted the superior efficacy of extended and more frequent sit-to-stand training (45 minutes, 5 sessions per week) in enhancing hip extensor strength. Hand-held dynamometry was utilized to quantify lower limb extensor strength within a cohort of 66 stroke survivors compared to general exercise protocols in the study.

Furthermore, step-up-and-down training has been shown to significantly improve gait parameters. For example, multi-directional and unstable support training modalities yielded significant improvements in gait parameters, with outcomes being notably superior to those of conventional exercises and stable support methods [63-64].

Heel raise training also demonstrated efficacy in enhancing balance among stroke survivors. Heel raise training, alone or adding into gait training, increased static balance significantly [65-66]. These improvements were measured using the Berg Balance Scale [66] and the Biodex Balance System, respectively. Collectively, these findings underscore the value of targeted task-oriented exercises in optimizing physical recovery and functional outcomes for stroke survivors.

Intervention effects sustainability

Bonferroni post hoc analyses (Table 5) demonstrated that the experimental group maintained DGI, 6mWT and the physical component summary score of the SF-36 at three months and six months follow-up. The benefits observed in the 30-second Chair Rise test were also maintained at six months. In contrast, improvements in DGI within the control group were sustained only up to three months.

The incorporation of elements such as visual cueing, auditory stimuli, boxing maneuvers, inter-limb coordination, competitive and challenging activities, engaging and enjoyable tasks and dual-task dynamic movements in our study has significantly enriched the rehabilitation environment. These activity arcade as described in the study intervention somewhat contributes to foster sustained improvements among stroke survivors. Notably, our follow-up findings align with those of other studies examining enriched rehabilitation environments, further substantiating the efficacy of these multidimensional approaches in promoting longer-term functional recovery and adaptability in stroke rehabilitation.

Functional and cognitive ability outcomes continued to improve with three to eight weeks enriched environment training and these improvements were maintained for three to six months after the intervention period in several past studies [48, 67-69]. At a 3-month follow up, the significant reduction in depression score were maintained after adding “Activity Arcade” and music listening of enriched environment training into usual rehabilitation [67-68]. At discharge, stroke survivors who underwent additional 2-hour “Activity Arcade” session along with daily ward activities 5 days in a week demonstrated significant improvements in depression, stress, cognitive function and motor function in these studies. These gains were sustained at three months follow-up. In these studies, the “Activity Arcade” session comprised computers with internet access and Skype, workstations for upper and lower limb exercises utilizing computer/television-based sensor and game technology, a library stocked with reading materials (books, audio-books, magazines, and newspapers), a music station and a simulated shopping corner featuring grocery items [67]. A study by Sarkamo et al. (2008) [68] also reported significant reduction of depression through Profile of Mood States among 54 stroke survivors after music listening either favourite genre or narrated audio books. Compared to the control group, the intervention group which received standard medical care and rehabilitation plus the study intervention showed maintenance of improvements up to the three months follow-up.

Enriched environment training with gaming elements demonstrated effectiveness in sustaining its benefits over a 6-month period post-implementation, irrespective of the stroke stage, ranging from acute to chronic phases [48, 69]. Compared to the usual care group, stroke survivors receiving enriched environment training spent a significantly higher proportion of their day engaged in "any activity" (71% versus 58%, respectively; $p<0.05$) [69]. The enriched environment, the implementation of which resulted in sustained changes for six months post-intervention included components such as iPads, books, puzzles, newspapers, games, music, magazines, audiobooks, word and number puzzles and board games. Another study by Vive et al. (2020) [48] revealed that the improvements of motor recover, balance, walking speed and aerobic endurance after combination physical therapy with social and cognitive stimulation (6 sessions per week for 3 weeks) were sustained at six months follow up.

Study limitations

This study acknowledges certain limitations. Firstly, to mitigate the potential influence of cognitive function on Checkercise® board performance, stroke survivors with a MoCA score below 22.1 were excluded. This exclusion, however, may limit the generalizability of the findings. Secondly, there was no monitoring of participants' physical activity levels during the follow-up period. These limitations warrant consideration in future research.

Conclusions

As the conclusion, Checkercise® demonstrably enhances long-term physical function and quality of life outcomes in stroke survivors, with these improvements sustained up to six months post-intervention. Key features of the Checkercise® board’s enriched environment included visual and auditory stimuli, boxing maneuvers, inter-limb coordination tasks, challenging activities and integrated dual-task movements, contributing to its sustained effectiveness. Further studies are however warranted to assess more effects of the gaming elements in the Checkercise® program.

Acknowledgement

The authors thank the National Medical Research and Ethics Committee, Ministry of Health for the study approval.

Author contributions

Conceptualization: Mohd Naqiuddin Johar and Nor Azlin Mohd Nordin

Funding acquisition: Nor Azlin Mohd Nordin

Methodology: Mohd Naqiuddin Johar and Nor Azlin Mohd Nordin

Supervision: Nor Azlin Mohd Nordin and Aznida Firzah Abdul Aziz

Writing-original draft: Mohd Naqiuddin Johar

Writing-review & editing: Nor Azlin Mohd Nordin

Funding

This study is partly funded by Universiti Kebangsaan Malaysia as this is a post-graduate (PhD) project and all equipment to be used in this study are properties of the university.

Conflict of interest: The authors report no conflicts of interest.

References

1. World Health Organization. (2024). The top 10 causes of death.
2. Krishnamurthi, R. V., Ikeda, T. & Feigin, V. L. (2020). Global, regional and country-specific burden of ischaemic stroke, intracerebral haemorrhage and subarachnoid haemorrhage: A systematic analysis of the Global Burden of Disease Study 2017. *Neuroepidemiology, 54*(Suppl. 2), 171–179.
3. Feigin, V. L., Vos, T., Alahdab, F., Amit, A. M. L., Bärnighausen, T. W., Beghi, E., Beheshti, M. et al. (2021). Burden of Neurological Disorders across the United State from 1990-2017: A Global Burden of Disease Study. *JAMA Neurology, 78*(2), 165–176.
4. World Health Organization. (2021). Retrieved from http://www.emro.who.int/health-topics/stroke-cerebrovascular-accident/index.html.
5. Wijaya, H. R., Supriyanto, E., Salim, M. I. M., Siregar, K. N. & Eryando, T. (2019). Stroke management cost: Review in Indonesia, Malaysia and Singapore. AIP Conference Proceedings, 2092, 30022. *American Institute of Physics Inc*.
6. Heart & Stroke Foundation. (2015). Stroke rehabilitation evidence tables: Mobility, Balance and Transfers. Canadian Stroke Best Practice Recommendations.

7. Alatawi, S. (2021). Current clinical practices of Saudi physiotherapists in stroke rehabilitation. *Journal of Acute Care Physical Therapy, 12*(4), 194–204.
8. Ali, H. U., Shafique, K., Rehman, T. ur, Shah, A. A., Younas, M. W., Khan, K. & Idrees, K. (2021). Treatment and assessment preferences for the management of stroke among physical therapists working in clinical settings. *Indo American Journal of Pharmaceutical Sciences, 8*(2), 159–165.
9. Amanzonwé, E. R., Kossi, O., Noukpo, S. I., Adoukonou, T., Hansen, D., Triccas, L. T. & Feys, P. (2023). Physiotherapy practices in acute and sub-acute stroke in a low resource country: A prospective observational study in Benin. *Journal of Stroke and Cerebrovascular Diseases, 32*(11).
10. Mpemba, M., Shula, H. & Chiluba, B. (2020). Stroke disability and physiotherapy interventions: A quantitative evaluation of physiotherapy treatment approaches' in Zambia. *IJDS Indonesian Journal of Disability Studies, 7*(1), 92–100.
11. American Heart Association Stroke Council. (2016). Guidelines for Adult Stroke Rehabilitation and Recovery. *Stroke, 47*(6), e98–e169.
12. Ali, M., Khan, S. U. & Asim, H. A. B. (2020). Effects of individual task specific training verses group circuit training on balance and ambulation in sub-acute stroke. *Rawal Medical Journal, 45*(1), 233–235.
13. Bovonsunthonchai, S., Aung, N., Hiengkaew, V. & Tretriluxana, J. (2020). A randomized controlled trial of motor imagery combined with structured progressive circuit class therapy on gait in stroke survivors. *Scientific Reports 2020 10*:1, 10(1), 1–11.
14. Kang, D., Park, J., Jeong, I. & Eun, S.-D. (2022). Comparing the effects of multicomponent exercise with or without power training on the cardiorespiratory fitness, physical function, and muscular strength of patients with stroke: a randomized controlled trial. *J Sports Med Phys Fitness, 62*(5), 722–731.
15. Martins, J. C., Nadeau, S., Aguiar, L. T., Scianni, A. A., Teixeira-Salmela, L. F. & De Morais Faria, C. D. C. (2020). Efficacy of task-specific circuit training on physical activity levels and mobility of stroke patients: A randomized controlled trial. *NeuroRehabilitation, 47*(4), 451–462.
16. Pillai, S. G. K., Nordin, N. A. M., Singh, D. K. A. & Culpan, J. (2016). Is circuit class therapy packaged to improve functional mobility, balance, community reintegration, and quality of life in stroke survivors? A review. *Malaysian Journal of Public Health Medicine, 16*(3), 75–86.
17. National Institute of Health and Care Excellence. (2023). Stroke rehabilitation in adults: Evidence reviews for the clinical and cost-effectiveness of music therapy for adults after a stroke. *NICE Clinical Guidelines*. Retrieved from www.nice.org.uk/guidance/cg162
18. Carrillo, C., Tilley, D., Horn, K., Gonzalez, M., Coffman, C., Hilton, C. & Mani, K. (2023). Effectiveness of robotics in stroke rehabilitation to accelerate upper extremity function: Systematic review. *Occupational Therapy International*, 2023.
19. Park, Y., Lee, D. & Lee, J. (2024). A comprehensive review : Robot-assisted treatments for gait rehabilitation in stroke patients. *Medicina, 60*, 620.
20. Wang, L., Zheng, Y., Dang, Y., Teng, M., Zhang, X., Cheng, Y., Zhang, X. et al. (2021). Effects of robot-assisted training on balance function in patients with stroke: A systematic review and meta-analysis. *Journal of Rehabilitation Medicine, 53*(4).
21. Chang, H., Song, Y. & Cen, X. (2022). Effectiveness of augmented reality for lower limb rehabilitation: A systematic review. *Applied Bionics and Biomechanics*, 2022.
22. Domínguez-Téllez, P., Moral-Muñoz, J. A., Salazar, A., Casado-Fernández, E. & Lucena-Antón, D. (2020). Game-based virtual reality interventions to improve upper limb motor function and quality of life after stroke: Systematic review and meta-analysis. *Games for Health Journal, 9*(1), 1–10.
23. Lin, C., Ren, Y. & Lu, A. (2023). The effectiveness of virtual reality games in improving cognition, mobility, and emotion in elderly post-stroke patients: A systematic review and meta-analysis. *Neurosurg Rev, 46*(1), 167.
24. Mazeas, A., Duclos, M., Pereira, B. & Chalabaev, A. (2022). Evaluating the effectiveness of gamification on physical activity: Systematic review and meta-analysis of randomized controlled trials. *Journal of Medical Internet Research, 24*(1).
25. Johar, M. N. & Mohd Nordin, N. A. (2022). Web-based game-focused exercise in the home setting as an alternative to hospital-based exercise for stroke survivors : A case study. *Malaysian Physiotherapy Journal, 1*(1), 62–68.
26. Ajit Singh, D. K., Mohd Nordin, N. A., Aziz, N. A. A., Lim, B. K. & Soh, L. C. (2013). Effects of substituting a portion of standard physiotherapy time with virtual reality games among community-dwelling stroke survivors. *BMC Neurology*, 13.
27. Johar, M. N., Nordin, N. A. M. & Aziz, A. F. A. (2022). The effect of game-based in comparison to conventional circuit exercise on functions, motivation level, self-efficacy and quality of life among stroke survivors. *Medicine, 101*(2), 1-7.
28. Johar, M. N., Mohd Nordin, N. A. & Mohd Yusoff, Y. A. (2022). Effects of game-based task-oriented circuit training on physical functions of stroke survivors: A pilot study in a state hospital in Kelantan, Malaysia. *Asian Journal of Medicine and Biomedicine, 5*(S2), 5–14.
29. Jones, C. J., Rikli, R. E. & Beam, W. C. (1999). A 30-second chair-stand test as a measure of lower body strength in community-residing older adults. *Research Quarterly for Exercise and Sport, 70*(2), 113–119.
30. Vereeck, L., Wuyts, F., Truijen, S. & Van de Heyning, P. (2008). Clinical assessment of balance: Normative data, and gender and age effects. *International Journal of Audiology, 47*(2), 67–75.
31. Jonsdottir, J. & Cattaneo, D. (2007). Reliability and validity of the dynamic gait index in persons with chronic stroke. *Archives of Physical Medicine and Rehabilitation, 88*(11), 1410–1415.
32. Lin, J. H., Hsu, M. J., Hsu, H. W., Wu, H. C. & Hsieh, C. L. (2010). Psychometric comparisons of 3 functional ambulation measures for patients with stroke. *Stroke, 41*(9), 2021–2025.
33. Steffen, T. M., Hacker, T. A. & Mollinger, L. (2002). Age and gender-related test performance in community-dwelling elderly people: six-minute walk test, berg balance scale, timed up & go test and gait speeds. *Physical Therapy, 82*(2), 128–137.
34. Eng, J. J., Dawson, A. S. & Chu, K. S. (2004). submaximal exercise in persons with stroke: test-retest reliability and concurrent validity with maximal oxygen consumption. *Archives of Physical Medicine and Rehabilitation, 85*(1), 113–118.
35. Kosak, M. & Smith, T. (2005). Comparison of the 2-, 6-, and 12-minute walk tests in patients with stroke. *Journal of Rehabilitation Research and Development, 42*(1), 103–108.
36. Dorman, P., Slattery, J., Farrell, B., Dennis, M. & Sandercock, P. (1998). Qualitative comparison of the reliability of health status assessments with the EuroQol and SF-36 questionnaires after stroke. *Stroke, 29*(1), 63–68.
37. Katona, M., Schmidt, R., Schupp, W. & Graessel, E. (2015). Predictors of health-related quality of life in stroke patients after neurological inpatient rehabilitation: A prospective study. *Health and Quality of Life Outcomes, 13*(1), 58:1-7.

38. Ojo Owolabi, M. (2010). Psychometric properties of the HRQOLISP-40: A novel, shortened multiculturally valid holistic stroke measure. *Neurorehabilitation and Neural Repair, 24*(9), 814–825.

39. Cohen, J. (2013). Statistical power analysis for the behavioral sciences 2nd edition. New York: Routledge.

40. Eichinger, F. L. F., Soares, A. V., Noveletto, F., Sagawa Júnior, Y., Bertemes Filho, P. & Domenech, S. C. (2020). Serious game for locomotor rehabilitation of hemiparetic stroke patients. *Fisioterapia em Movimento, 33*, 15-25.

41. Kim, I. C. & Lee, B. H. (2012). Effects of augmented reality with functional electric stimulation on muscle strength, balance and gait of stroke patients. *Journal of Physical Therapy Science, 24*(8), 755–762.

42. Frigon, A. (2017). The neural control of interlimb coordination during mammalian locomotion. *Journal of Neurophysiology, 117*(6), 2224–2241.

43. Lin, P. L., Yu, L. F., Kuo, S. F., Wang, X. M., Lu, L. H. & Lin, C. H. (2022). Effects of computer-aided rowing exercise systems on improving muscle strength and function in older adults with mild knee osteoarthritis: a randomized controlled clinical trial. *BMC Geriatrics, 22*(1), 1–11.

44. Oza, N., Motar, P. & Deshmukh, N. (2021). Effect of elliptical training for balance and gait training in patients with chronic stroke: A case report 118–122.

45. de Rooij, I. J. M., van de Port, I. G. L., Punt, M., Abbink-Van Moorsel, P. J. M., Kortsmit, M., van Eijk, R. P. A., Visser-Meily, J. M. A. et al. (2021). Effect of virtual reality gait training on participation in survivors of subacute stroke: A randomized controlled trial. *Physical Therapy, 101*(5), 1–10.

46. Akinci, M., Burak, M., Kasal, F. Z., Özaslan, E. A., Huri, M. & Kurtaran, Z. A. (2024). The effects of combined virtual reality exercises and robot assisted gait training on cognitive functions, daily living activities and quality of life in high functioning individuals with subacute stroke. *Perceptual and Motor Skills, 131*(3), 756–769.

47. Pang, M. Y. C., Yang, L., Ouyang, H., Lam, F. M. H., Huang, M. & Jehu, D. A. (2018). Dual-task exercise reduces cognitive-motor interference in walking and falls after stroke: A randomized controlled study. *Stroke, 49*(12), 2990–2998.

48. Vive, S., Af Geijerstam, J. L., Kuhn, H. G. & Bunketorp-Käll, L. (2020). Enriched, task-specific therapy in the chronic phase after stroke: An exploratory study. *Journal of Neurologic Physical Therapy, 44*(2), 144–155.

49. Lee, M.-M., Shin, D.-C. & Song, C.-H. (2016). Canoe game-based virtual reality training to improve trunk postural stability, balance, and upper limb motor function in subacute stroke patients: a randomized controlled pilot study. *J. Phys. Ther. Sci., 28*, 2019–2024.

50. Anwar, N., Karimi, H., Ahmad, A., Gilani, S. A., Khalid, K., Aslam, A. S. & Hanif, A. (2022). Virtual reality training using Nintendo Wii games for patients with stroke: Randomized controlled trial. *JMIR Serious Games, 10*(2), 1–8.

51. Hollands, K. L., Pelton, T. A., Wimperis, A., Whitham, D., Tan, W., Jowett, S., Sackley, C. M. et al. (2015). Feasibility and preliminary efficacy of visual cue training to improve adaptability of walking after stroke: Multi-centre, single-blind randomised control pilot trial. *PLoS ONE, 10*(10).

52. Huang, W. Y., Tuan, S. H., Li, M. H. & Hsu, P. Te. (2022). Efficacy of a novel walking assist device with auxiliary laser illuminator in stroke Patients~ a randomized control trial. *Journal of the Formosan Medical Association, 121*(3), 592–603.

53. Shin, J. & Chung, Y. (2022). The effects of treadmill training with visual feedback and rhythmic auditory cue on gait and balance in chronic stroke patients: A randomized controlled trial. *NeuroRehabilitation, 51*(3), 443–453.

54. Fahmy, M., Samir, E., Sharaf, M. A., Gharib, N. M., Shendy, W., Salem, Y., Samir, H. et al. (2024). Effectiveness of virtual reality based aerobic exercise on walking endurance, gait kinematics, and function in patients with chronic stroke: A double blinded randomized controlled trial. *Fizjoterapia Polska, 24*(3), 293–302.

55. Akinci, M., Burak, M., Yaşar, E. & Kılıç, R. T. (2023). The effects of robot-assisted gait training and virtual reality on balance and gait in stroke survivors: A randomized controlled trial. *Gait and Posture, 103*(May), 215–222.

56. Sánchez-Lastra, M. A., Ayán, C., Sener, M. & Cancela, J. M. (2020). The use of adapted boxing as a rehabilitation strategy in people with diverse health conditions: A systematic review. *European Journal of Adapted Physical Activity, 13*(1), 1–17.

57. Hurkmans, H. L., Ribbers, G. M., Streur-Kranenburg, M. F., Stam, H. J. & Van Den Berg-Emons, R. J. (2011). Energy expenditure in chronic stroke patients playing Wii Sports: A pilot study. *Journal of NeuroEngineering and Rehabilitation, 8*(1), 1–7.

58. Kafri, M., Myslinski, M. J., Gade, V. K. & Deutsch, J. E. (2014). Energy expenditure and exercise intensity of interactive video gaming in individuals poststroke. *Neurorehabilitation and Neural Repair, 28*(1), 56–65.

59. Fonte, G., Schreiber, C., Areno, G., Masson, X., Chantraine, F., Schütz, G. & Dierick, F. (2022). Metabolic energy expenditure and accelerometer: Determined physical activity levels in post-stroke hemiparetic patients. *J Stroke Cerebrovasc Dis, 31*(5), 106397.

60. Amala, S. & Chippala, P. 2024. Effect of sit-to-stand training on balance, muscle strength and activities of daily living in patients with stroke: A randomised controlled trial. *Journal of Clinical and Diagnostic Research*, 5–8.

61. de Sousa, D. G., Harvey, L. A., Dorsch, S., Varettas, B., Jamieson, S., Murphy, A. & Giaccari, S. (2019). Two weeks of intensive sit-to-stand training in addition to usual care improves sit-to-stand ability in people who are unable to stand up independently after stroke: a randomised trial. *Journal of Physiotherapy, 65*(3), 152–158.

62. Tung, F. L., Yang, Y. R., Lee, C. C. & Wang, R. Y. (2010). Balance outcomes after additional sit-to-stand training in subjects with stroke: A randomized controlled trial. *Clinical Rehabilitation, 24*(6), 533–542.

63. Oh, G.-S., Choi, Y.-R., Bang, D.-H. & Cha, Y.-J. (2017). Effects of step-up training on walking ability of stroke patients by different support surface characteristics. *Journal of The Korean Society of Physical Medicine, 12*(3), 99–104.

64. Vats Manju. (2013). Efficacy of task specific step-up exercises on the gait parameters of chronic hemiparetic stroke individuals. *International Journal of Physiotherapy and Research, 1*(4), 130–137.

65. Lee, S. M., Cynn, H. S., Yoon, T. L. & Lee, J. H. (2017). Effects of different heel-raise-lower exercise interventions on the strength of plantarflexion, balance, and gait parameters in stroke survivors. *Physiotherapy Theory and Practice, 33*(9), 706–715.

66. Putri, W. E. & Farid, R. (2021). Effectiveness heel-raise-lower exercise and dual task gait training against a patient reversible ischemic neurologic deficit stroke to improve: A case study. *Academic Physiotherapy Conference Proceeding*, 957–966.

67. Khan, F., Amatya, B., Elmalik, A., Lowe, M., Ng, L., Reid, I. & Galea, M. P. (2016). An enriched environmental programme during inpatient neuro-rehabilitation: A randomized controlled trial. *Journal of Rehabilitation Medicine, 48*(5), 417–425.

68. Särkämö, T., Tervaniemi, M., Laitinen, S., Forsblom, A., Soinila, S., Mikkonen, M., Autti, T. et al. (2008). Music listening enhances cognitive recovery and mood after middle cerebral artery stroke. *Brain, 131*(3), 866–876.

69. Rosbergen, I. C. M., Grimley, R. S., Hayward, K. S., Walker, K. C., Rowley, D., Campbell, A. M., McGufficke, S. et al. (2017). Embedding an enriched environment in an acute stroke unit increases activity in people with stroke: A controlled before-after pilot study. *Clinical Rehabilitation, 31*(11), 1516–1528.