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ORIGINAL ARTICLE

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

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ABSTRAK

Pemandiri strok kerap mengalami kemerosotan fungsi yang menjejaskan tahap kendiri dan kualiti hidup. Senaman litar terbukti memberi manfaat, namun bukti mengenai integrasi elemen permainan dalam rehabilitasi masih terhad. Checkercise®, iaitu senaman litar berasaskan permainan yang inovatif, dibangunkan untuk menggabungkan latihan terapeutik dengan pengalaman interaktiviti yang menyeronokkan. Kajian ini menilai keberkesanannya berbanding senaman litar konvensional. Satu kajian rawak terkawal telah dijalankan melibatkan 88 pemandiri strok subakut (min umur = 58.6 ± 9.9 tahun) yang dibahagikan kepada kumpulan kajian (Checkercise®) atau kawalan. Kedua-dua kumpulan mengikuti sesi latihan berjadual dua kali seminggu selama 12 minggu di bawah pengawasan ahli fisioterapi. Ukuran hasil meliputi ujian duduk berdiri 30 saat (kekuatan kaki), Dynamic Gait Index (DGI) (kestabilan badan), ujian berjalan 6 minit (ketahanan aerobik) dan soal selidik Short Form-36 (SF-36) (kualiti hidup). Penilaian dilakukan pada peringkat awal (pra-ujian), minggu ke-12, ke-24 dan ke-36. Analisis menggunakan mixed model ANOVA telah dijalankan. Hasil kajian menunjukkan kesan interaksi yang signifikan ($p < 0.05$) dengan saiz kesan yang kecil (0.03–0.04) terhadap ujian duduk berdiri 30 saat dan skor fizikal serta mental SF-36, dengan peningkatan lebih besar dalam kumpulan kajian (ujian duduk berdiri 30 saat: +34%; skor fizikal SF-36: +41%; skor mental SF-36: +29%) berbanding kumpulan kawalan. Kesan kumpulan kajian yang signifikan ($p < 0.05$) dengan saiz kesan kecil (0.04–0.05) turut dicatat untuk DGI (+18% berbanding +16%) dan ujian berjalan 6 minit (+30% berbanding +25%). Analisis post hoc mengesahkan peningkatan prestasi yang berkekalan sehingga 6 bulan ($p < 0.05$) dalam kumpulan kajian bagi ujian duduk berdiri 30 saat (10%), DGI (4%), ujian berjalan 6 minit (12.8%), dan komponen fizikal soal selidik SF-36 (8.9%), manakala kumpulan kawalan hanya mengekalkan peningkatan pada DGI sahaja (4.5%). Kesimpulannya, Checkercise® berkesan dalam meningkatkan serta mengekalkan fungsi fizikal dan kualiti hidup, seterusnya berpotensi sebagai strategi rehabilitasi yang menarik dan berkesan.

Kata kunci: *Fungsi; kualiti hidup; strok*

ABSTRACT

Stroke survivors often experience functional decline that limits independence and reduces quality of life. Circuit exercise enhances functional outcomes; however, evidence on incorporating gaming into rehabilitation remains scarce. Checkercise®, a novel game-based circuit exercise, was developed to integrate therapeutic training with engaging gameplay. This study examined its effectiveness compared with conventional circuit exercise. A parallel randomised controlled trial was conducted with 88 subacute stroke survivors (mean age = 58.6 $\pm$ 9.9 years), randomised to experimental (Checkercise®) or control groups. Both groups received supervised sessions twice weekly for 12 weeks. Outcomes included the 30-second chair rise test (lower limb strength), Dynamic Gait Index (DGI) (dynamic balance), 6-minute Walk Test (6mWT) (aerobic endurance) and Short Form-36 (SF-36) (quality of life). Assessments were performed at baseline (pre-assessment) and at 12, 24 and 36 weeks. Mixed-model ANOVA was used for analysis. Results showed significant interaction effects ($p < 0.05$) with a small effect size (0.03–0.04) for lower limb strength and SF-36 physical and mental scores, with greater improvements in the experimental group (30 second chair rise test: +34%; SF-36 physical: +41%; mental: +29%) versus controls. Significant group effects ($p<0.05$) with a small effect size (0.04–0.05) were also observed for DGI (+18% versus +16%) and 6mWT (+30% versus +25%). Post hoc analyses demonstrated sustained improvements at six months ($p < 0.05$) for 30-second chair rise test (10%), DGI (4%), 6mWT (12.8%) and the SF-36 physical scores (8.9%) in the experimental group, while the control group retained gains only in DGI (4%) ($p<0.05$). In conclusion, Checkercise® was effective in improving and sustaining physical functions and quality of life, supporting its potential as an engaging rehabilitation strategy.

Keywords: Function; quality of life; stroke

INTRODUCTION

Cerebrovascular accident or stroke, constituted the third leading cause of global mortality in 2021, accounting for approximately 10% of total deaths worldwide (World Health Organisation 2024). In addition, stroke-related disability is the leading cause of disability worldwide (Krishnamurthi et al. 2020). 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 (Feigin et al. 2021). 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 (World Health Organisation 2021). 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 (Wijaya et al. 2019). Physical activity levels following stroke (Buvarp et al. 2023), sedentary behaviour (Jiang et al. 2025) and employment status (Dujovic et al. 2025) have been identified as significant predictors of stroke rehabilitation outcomes. These findings underscore the necessity of incorporating such confounding variables into the design of personalised and context-sensitive rehabilitation strategies to optimise recovery.

Rehabilitation is central to post-stroke care, with a specific focus on minimising 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 utilised 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 specialised methods like motor relearning and the Bobath approach (Heart & Stroke Foundation 2019). In many countries, post-stroke rehabilitation services are initiated during hospitalisation 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 (Alatawi 2021; Ali et al. 2021; Amanzonwé et al. 2023; Mpemba et al. 2020). 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 (Winstein et al. 2016). 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 (Ali et al. 2020; Bovonsunthonchai et al. 2020; Kang et al. 2022; Martins et al. 2020). Although it is normally organised 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 (Pillai et al. 2016; National Institute of Health and Care Excellence 2023).

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 (Carrillo et al. 2023; Park et al. 2024; Wang et al. 2021) or virtual reality-based therapy (Chang et al. 2022; Domínguez-Téllez et al. 2020; Lin et al. 2023; Mazeas et al. 2022); with the individual session potentially conducted as a home-based exercise program (Johar & Mohd Nordin 2022).

A recent systematic review of 169 studies from 2019 to 2023 (n = 6404) demonstrated that game-based not only improved motor and cognitive function but also had a significant positive impact on stroke survivors' emotional, social and personal levels in comparison to conventional stroke rehabilitation (Sánchez-Gil et al. 2025). Before initiating gamebased stroke rehabilitation, stroke survivors are required to meet specific clinical criteria, including adequate motor and cognitive function to interact safely with the technology, as well as sufficient cognitive and emotional readiness to engage effectively in the intervention (Sánchez-Gil et al. 2025).

Game-based exercise may have fundamental advantages compared to conventional exercise, as they promote active learning and sustained motivation, providing a task-oriented training platform with adaptable difficulty tailored to individual motor capabilities and rehabilitation needs (Perry et al. 2020). Despite the expanding utilisation 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 personalised 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 (Singh et al. 2013). 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 6 months post-intervention.

MATERIALS AND METHODS

Study Design and Setting

The present study employed an assessor-blinded randomised 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, 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 had been published elsewhere (Johar et al. 2022a).

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 $\pm$ 10.8 years and a mean body mass index of 25.8 $\pm$ 5.4 kg/m^2, whom referred for physiotherapy at the identified hospital were initially screened. The required sample size for this study was calculated using G*power, version 3.1 ((Heinrich-Heine-Universitat, Dusseldorf, Germany) software for ANOVA repeated measures, within-between interactions. A medium effect size (Cohen's f = 0.25), derived from Outermans et al. (2010), was assumed, with a statistical power of 80% and a two-sided statistical level of alpha of 0.05. The analysis indicated a required minimum sample size of 82 participants. 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: (i) clinically diagnosed haemorrhagic or ischemic stroke, confirmed by a physician; (ii) age range between 40 to 80 years; and (iii) 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: (i) a score of 22.1 or below on the Montreal Cognitive Assessment (MoCA), indicating cognitive impairment; (ii) medical conditions such as severe musculoskeletal disorders, unstable angina or uncontrolled hypertension that would significantly limit physical functionality; (iii) chronic central nervous system pathology other than stroke such as Parkinson's disease and polyneuropathy; (iv) Modified Rankin Scale (mRS) score of 4 or higher, indicating moderate-severe to severe disability; (v) participation in home-based physiotherapy or received traditional therapeutics services following discharge from an inpatient setting; and (vi) visual field defects.

Group Allocation and Blinding

Recruited participants were randomised into either the experimental group or the control group using stratified block randomisation 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 to 75 years) and disability level (mRS score of 2 or less; mRS score of 3). An independent researcher performed the randomisation 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 featured a design replicating the 'snake and ladder' game (Figure 1). The exercise protocol, adhering to the frequency, intensity, time and type (FITT) principle, was summarised in Table 1.

Participants commence by positioning their counter on the space designated "start." Subsequently, each participant sequentially rolled a dice once as part of the standardised game procedure to ensure randomisation and maintained engagement throughout the intervention. 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 was 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" were 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 was defined by each participant's arrival at the space designated "finish" with the first participant to do so identified as the winner. Checkercise® was 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 introduced a novel integration of resistance, balance and aerobic exercises within a gamified framework. Resistance exercises emphasised inter-limb coordination through tasks such as dumbbell lifting during seated-to-standing transitions, squats with step-ups and step-downs, and hip

FIGURE1: Design of the Checkercise® board

TABLE 1: Description of the Checkercise® board exercises

Formula	Resistance exercise	Balance exercise	Aerobic exercise
	Repeated sit to stand	Walking on balance beam	Alternate jab
Frequency	2 sessions per week	2 sessions per week	2 sessions per 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	Repeated jab punching
Progression	Alternate seated to standing (Lifting up 2 kg of dumbbell)	Tandem walking	Repeated double jab punching with defense
	Repeated partial squat	Figure of 8 walking	Alternate hook
Frequency	2 sessions per week	2 sessions per week	2 sessions per 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	Repeated hook punching
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
	Repeated step-up and down	Walking with instruction	Double jab and hook
Frequency	2 sessions per week	2 sessions per week	2 sessions per 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 and stop (closed eyes in static standing)	Repeated double jab punching with hook
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 and squat
	Repeated hip raise	Walk and touch cones	Double jab
Frequency	2 sessions per week	2 sessions per week	2 sessions per 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 and touch cones cuboid shape	Repeated double jab punching with defense and kick
Progression	Standing, alternate steps-ups on the 8-inches step board (Lifting up 2 kg of dumbbell/speed at 50 beats per minute)	Walk and touch cones hexagon shape	Repeated double jab punching with squat

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Formula	Resistance exercise	Balance exercise	Aerobic exercise
	Repeated heel raise	Backward walking	Cross straight
Frequency	2 sessions per week	2 sessions per week	2 sessions per 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	Repeated cross straight punching
Progression	Standing, alternate raises heel (Lifting up 2 kg of dumbbell/ speed at 75 beats per minute)	Backward walking	Repeated 4 times cross straight punching with squat

and heel raises. Balance exercises involved 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 comprised progressive boxing sequences, ranging from basic punches (jab, hook and 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. 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 (Johar et al. 2022a).

Each exercise bout within the protocol was standardised to a duration of two minutes, followed by a two-minute rest interval. The complete Checkercise® protocol encompassed an average of ten distinct exercises, with an anticipated total session duration averaging 40 minutes. For safety and feasibility considerations, participants were allowed a 2-minute rest interval between exercise stations to prevent fatigue accumulation and ensure optimal performance. Their perceived exertion levels were assessed using the Borg Rating of Perceived Exertion scale. To ensure protocol fidelity and evaluate exercise intensity, session attendance was systematically documented using attendance checklists together with the perceived exertion levels for each station in the respective session. Participants were instructed to refrain from performing any exercise activities outside the designated intervention sessions to minimise potential confounding effects on recovery outcomes throughout the study period.

A pilot study was conducted to examine the effects of a game-based circuit exercise using the Checkercise® board on physical function and quality of life among stroke survivors. The study was carried out at the Physiotherapy Unit, Hospital Raja Perempuan Zainab II, Kota Bharu between August 2019 and October 2020 (Johar et al. 2022b). Thirty stroke survivors with mild to moderate disability (mRS levels 1–3) and a mean age of 66 years participated. The intervention involved Checkercise® sessions lasting 40 minutes, twice weekly for 12 weeks. Following the intervention, significant improvements were observed in lower limb strength, as indicated by the 30-second chair stand test [$t(1,29) = 66.69$, $p < 0.05$, $d = 0.5$], dynamic balance measured using the Dynamic Gait Index (DGI) [$t(1,29) = 56.44$, $p < 0.05$, $d = 0.5$] and aerobic endurance assessed via the 6-minute walk test (6mWT) [$t(1,29) = 48.70$, $p < 0.05$, $d = 0.6$], corresponding to gains of 9%, 7% and 23%, respectively. Quality of life

(QoL) also improved significantly with moderate effect sizes for the Short Form-36 (SF-36) physical (d = 0.44), mental (d = 0.43) and combined components (d = 0.48). These findings indicated that Checkercise® circuit training may enhance physical performance and QoL among stroke survivors, supporting its potential application in post-stroke rehabilitation programs.

A conventional circuit training program protocol employed in this study was developed in accordance with international stroke rehabilitation guidelines (Intercollegiate Stroke Working Party 2023; Teasell et al. 2020; Winstein et al. 2016). These guidelines consistently highlight the integration of resistance and aerobic exercises as the core components of physical function recovery (Intercollegiate Stroke Working Party 2023; Winstein et al. 2016), while the inclusion of balance exercise is additionally recommended to enhance postural stability and minimise fall risk among stroke survivors (Teasell et al. 2020). Each session was structured to accommodate five participants, rotating systematically through six designated exercise stations. These stations were comprised of: (i) cycling; (ii) repeated sit to stand exercises; (iii) repeated arm curl exercises, (iv) repeated hip and heel raise exercises, (v) step up and down exercises and (vi) 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. The conventional exercise protocol, adhering to the FITT principle, was summarised in Table 2.

The actual load progression and total repetitions completed in the Checkercise® training group were superior to those achieved by the conventional training group. Metronome cues were systematically integrated into the

TABLE 2: Description of the conventional exercises

Formula	Upper body resistance exercise	Knee control stability exercise	Aerobic exercise
	Repeated arm curl	Step up and down	Cycling
Frequency	2 sessions per week	2 sessions per week	2 sessions per week
Intensity	Comfortable pace	Comfortable pace	Comfortable pace
Time	5 minutes	5 minutes	5 minutes
Technique	Repeated arm curl (without load)	Step-up and down (without load)	Slow speed (medium resistance)
Progression	Repeated arm curl (Lifting up 2 kg of dumbbell)	Step-up and down (Lifting up 2 kg of dumbbell)	Moderately fast speed (heavy resistance)
	Lower body resistance exercise	**Static balance exercise**	**Dynamic balance exercise**
	Repeated sit to stand	Repeated hip raise	Obstacle walking
Frequency	2 sessions per week	2 sessions per week	2 sessions per week
Intensity	Comfortable pace	Comfortable pace	Comfortable pace
Time	5 minutes	5 minutes	5 minutes
Technique	Alternate seated to standing (without load)	Repeated hip raise (without load)	Tandem walking
Progression	Alternate seated to standing (Lifting up 2 kg of dumbbell)	Repeated hip raise (Lifting up 2 kg of dumbbell)	Obstacle walking

Checkercise® sessions to regulate tempo and progressively increase training volume, thereby maintaining a consistent challenge and promoting greater exercise endurance. Furthermore, the gradual addition of external resistance over time enhanced workout intensity and contributed to continuous overload. Similar to the application of progressive overload principles for exercise intensity in the experimental group, exercises in the control group were also optimised by gradually increasing task complexity and adding loads. The primary distinction between groups was that participants in the Checkercise® training group performed exercises in coordination with metronome cues to achieve the more total repetitions, whereas participants in the conventional training group performed exercises at a self-selected, comfortable pace without systematic load progression. However, exercise load progression in both group was not predetermined by a fixed timeline. Instead, participants advanced to higher load levels once they demonstrated satisfactory task performance, allowing progression to be individualised according to each participant's functional capacity.

Throughout a 12-week intervention period, participants engaged in the Checkercise® were supervised by the direct supervision of the primary researcher. Meanwhile for the control group, two physiotherapists with at least five years of professional experience supervised participants in performing conventional circuit exercises. Standardised verbal prompts were administered to both groups to ensure equivalent motivational support throughout the intervention.

Outcome Assessments

To determine the interventions effectiveness, the following outcome variables and standardised measures were employed: (i) 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 standardised 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, were reported to range from 14 to 17 repetitions for males and 13 to 15 repetitions for females (Jones et al. 1999). The 30-second chair stand test had 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) (Jones et al. 1999). (ii) Dynamic balance during ambulation was evaluated using the DGI. Normative data for the DGI in healthy individuals aged 50 to 79 years indicated a mean score range of 23.2 $\pm$ 0.9 to 23.9 $\pm$ 0.4 (Vereeck et al. 2008). 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 was scored on a 4-point ordinal scale ranging from 0 (indicating severe impairment) to 3 (representing normal performance). The DGI had demonstrated high test-retest reliability (ICC = 0.94 to 0.96) (Jonsdottir & Cattaneo 2007; Vereeck et al. 2008). Total DGI scores ranged from 0 to 24, with higher scores indicative of greater independence in functional mobility among individuals post-stroke. (iii) A 6mWT measured aerobic endurance by recording the distance participants walked over six minutes along a ten meters course. Normative data for the 6mWT in healthy individuals aged 50 to 79 years indicated a walked distance ranging from 357 to 697 meters for males and from 321 to 621 meters for females (Lin et al. 2010). It was 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 (Steffen et al. 2002). The 6mWT demonstrated high test-retest reliability (ICC = 0.99) (Eng et al. 2004; Kosak & Smith 2005). (iv)QoL was assessed using the Short Form-36 (SF-36) questionnaire, which evaluated participants' QoL across eight domains (36 questions) which covered: (1) physical health component, which included physical functioning (ten questions), role limitations due to physical health (four questions) and pain (two questions); (2) mental health component, which included 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 included general health (five questions) and energy/fatigue (four questions). The SF-36 had demonstrated moderate to high test-retest reliability in post-stroke individuals, with ICC ranging from 0.57 to 0.8 (Dorman et al. 1998; Katona et al. 2015; Ojo Owolabi et al. 2010). Total scores on the SF-36 range from 0 to 100, with higher scores indicative of a better QoL.

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 (pre-assessment), post-intervention (12 weeks) and at 12 and 24-week follow-up intervals. To mitigate assessor bias, baseline (pre-assessment) 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

All date were entered into Statistical Package for the Social Sciences (IBM Corp. Armonnk, NY, USA). A mixed model ANOVA was used to analyse 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 randomised 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. However, LOCF can make a treatment look more effective than it is, potentially leading to false-positive results. Sensitivity analyses using multiple imputation were conducted if dropout exceeded anticipated levels. Cohen (2013) had 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 was detailed in the CONSORT diagram (Figure 2). The game-based circuit exercise group included 44 participants (mean age = 58.6 $\pm$ 9.9 years), while the conventional circuit exercise group also consisted of 44 participants (mean age = 55.5 $\pm$ 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 3 showed the socio-demography and baseline (pre-assessment) 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 4 and 5 provided the descriptive and statistical indices for physical functions (30-second chair rise test, DGI and 6mWT) and QoL (SF-36) outcomes. Data from both the experimental and control groups were normally distributed, as indicated by the Shapiro-Wilk test ($p > 0.05$), confirming the appropriateness of subsequent parametric statistical analyses. A 2 x 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

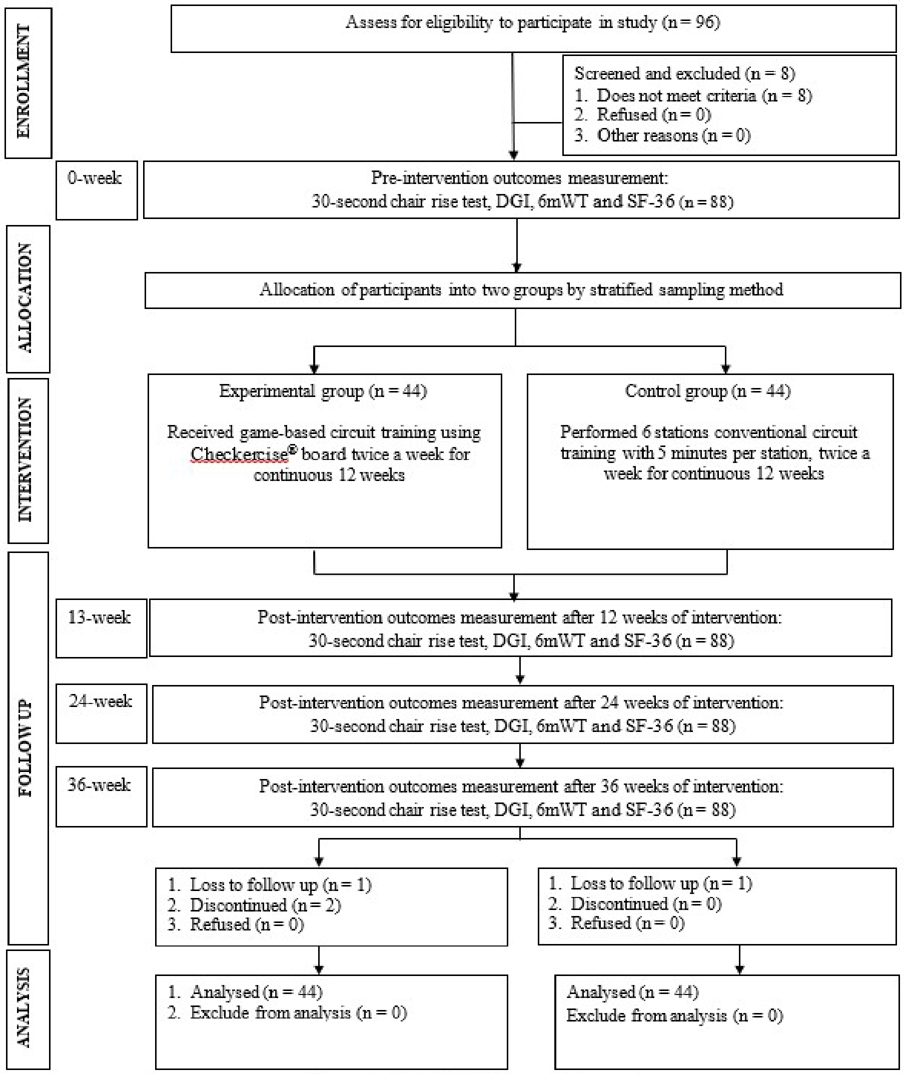

FIGURE 2: CONSORT diagram of the study

TABLE 3: Baseline for social demographic data and characteristics of participants

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

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Variables	Experimental group (n = 44)	Control group (n = 44)	p-value
Side of heamiparesis (Right)	50%	50%	1.0
Side of dominance (Right)	95%	100%	1.0
Body mass index (kg/m^2)	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

All data were presented as mean ± standard deviation with a p-value for Independent T-test, except for ethnicity, gender, age, 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; SF-36: Short Form-36 questionnaire

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 mobilisation techniques, stretching exercises and active-assisted movement therapy). Another study was conducted by Kim and Lee (2012) 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 (Eichinger et al. 2020; Kim & Lee 2012).

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, was theorised to improve limb control by enhancing neural coupling between arms and legs (Frigon 2017). An example of inter-limb coordination demonstrated during Checkercise® gameplay included 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,

TABLE 4: Comparison of changes in leg strength, posture stability and aerobic endurance between the two groups at baseline (pre-assessment) 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)	Changes	0-week	12-week	24-week (3-month follow-up)	36-week (6-month follow-up)	Changes	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

Values were presented as mean ± standard deviation; large effect size; #η^2, partial eta squared > 0.14 statistically significant; *p < 0.05 by Mixed Model ANOVA; DGI: Dynamic Gait Index; 6mWT: 6-minute walk test.

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 followed: 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 6) 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, improvement within the control group were sustained up to six months only in DGI score.

DISCUSSION

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 (Eichinger et al. 2020; Kim & Lee 2012). Eichinger et al. (2020) investigated whether

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TABLE 5: Comparison of changes in quality of life between the two groups at baseline (pre-assessment), 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)	Changes	0-week	12-week	24-week (3-month follow-up)	36-week (6-month follow-up)	Changes	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 (0.06)
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	*0.025 (0.04)
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	0.726

Values are presented as mean ± standard deviation; large effect size $^{\#}\eta^2$, partial eta squared >0.14 statistically significant, *p < 0.05 by Mixed Model ANOVA; SF-36: Short Form-36 questionnaire.

TABLE 6: 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

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

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

such as rowing and elliptical machine training, provided further evidence to highlight the significance of upper and lower limb coordination for lower limb strength (Lin et al. 2022; Oza et al. 2021). A recent randomised controlled pilot trial assessed the effectiveness of computerised rowing exercise as compared to the usual resistance exercise routine in 38 older individuals with knee osteoarthritis (Lin et al. 2022). 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 favouring the experimental group were found for hip and knee muscle strength. Another study, a case report by Oza et al. (2021) has concluded that elliptical training of three 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 (Lin et al. 2022; Oza et al. 2021).

Additionally, this outcome indicates a favourable dose response relationship facilitated by Checkercise® board training structured progression and game-based overload principles. The unique features of Checkercise®, including its integrated coordination demands, rule-based penalties and competitive gameplay, may have enhanced participants' motivation and attentional focus, promoting greater effort and motor learning. The need to avoid penalties and outperform peers may have encouraged higher quality repetitions and sustained effort, thereby maximising lower limb muscle recruitment. Collectively, these factors could explain the superior strength adaptations observed, emphasising the potential of gamified, progressively challenging circuit exercises to optimise lower limb recovery in post-stroke rehabilitation.

Following a 3-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 Rooij et al. (2021) and

Akinci et al. (2024) 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 QoL 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 Rooij et al. (2021) and Akinci et al. (2024) reported that game elements and variations in virtual reality gaming environments enhanced the QoL 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 and QoL 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) 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, such as verbal fluency and serial subtractions of three 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 (Vive et al. 2020). QoL improvements were measured using the Stroke-specific Quality of Life Scale (Pang et al. 2018) and the EuroQol 5-dimensions (Vive et al. 2020) in the experimental group were sustained at four to six months follow-up (Pang et al. 2018; Vive et al. 2020).

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) 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) 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 (Anwar et al. 2022; Lee et al. 2016).

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 eight 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 (Hollands et al. 2015; Huang et al. 2022; Shin & Chung 2022). Hollands et al. (2015) 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) 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 (Hollands et al. 2015; Huang et al. 2022; Shin & Chung 2022).

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) 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) 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 (Akinci et al. 2023; Fahmy et al. 2024), a significant increase in paretic step length was evident solely after the combined approach of Nintendo Wii Fit Plus aerobic games and conventional therapy (Fahmy et al. 2024).

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 optimised by progressively increasing the complexity of tasks and the tempo of the metronome beeps. In a systematic review, Sánchez-Lastra et al. (2020) 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, three experimental studies assessed the impact of boxing as a rehabilitation approach for stroke survivors. Among these three studies, two documented variations in heart rate and energy expenditure during virtual reality boxing exercises in stroke survivors (Hurkmans et al. 2011; Kafri et al. 2014). For stroke survivors, energy expenditure varied between 1.81 $\pm$ 0.7 METs during Wii™ sitting boxing and 3.46 $\pm$ 1.3 METs during Wii™ standing boxing. Exercise intensity for this group ranged from 49.8 $\pm$ 9.3% to 64.7 $\pm$ 9.3% of their predicted maximal heart rate. Conversely, both energy expenditure and exercise intensity were significantly lower in comparison to able-bodied participants (Kafri et al. 2014). Wii™ boxing has been classified as a hard-intensity activity, with a METs ranging from 3.46 to 4.1 (Hurkmans et al. 2011; Kafri et al. 2014). 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) (Fonte et al. 2022).

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 QoL. The primary objective of the conventional circuit training regimen employed in the control group is to emphasise 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 (Amala & Chippala 2024; de Sousa et al. 2019; Tung et al. 2010).. For instance, Tung et al. (2010) 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) found significant improvements in lower limb extensor strength when measured using an inclinometer among 30 stroke survivors. Amala and Chippala (2024) further highlighted the superior efficacy of extended and more frequent sit to stand training (45 minutes, five sessions per week) in enhancing hip extensor strength. Hand-held dynamometry was utilised 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 (Oh et al. 2014; Vats 2013).

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 (Lee et al. 2017; Putri & Farid 2021). These improvements were measured using the Berg Balance Scale (Putri & Farid 2021) and the Biodex Balance System, respectively. Collectively, these findings underscore the value of targeted task-oriented exercises in optimising physical recovery and functional outcomes for stroke survivors.

Intervention Effects Sustainability

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, improvement within the control group were sustained up to six months only in DGI score.

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 (Khan et al. 2016; Rosbergen et al. 2017; Sarkamo et al. 2008; Vive et al. 2020;). 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 (Khan et al. 2016; Sarkamo et al. 2008) 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 utilising 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 (Khan et al. 2016). A study by Sarkamo et al. (2008) 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 (Vive et al. 2020; Rosbergen et al. 2017). 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; $p < 0.05$) (Rosbergen et al. 2017). 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) revealed that the improvements of motor recover, balance, walking speed and aerobic endurance after combination physical therapy with social and cognitive stimulation (six sessions per week for three weeks) were sustained at six months follow-up.

Physical activity levels following stroke (Buvarp et al. 2023), sedentary behaviour (Jiang et al. 2025) and employment status (Dujovic et al. 2025) have been identified as significant predictors of stroke rehabilitation outcomes. These factors are not only associated with the rate of recovery but may also influence the persistence and sustainability of treatment effects over time. Participants with higher baseline physical activity levels and lower sedentary time are likely to demonstrate better retention of motor and functional outcomes, as they may continue to engage in active lifestyles that reinforce the therapeutic effects of Checkercise®. Employment status further reflects psychosocial readiness, environmental support and access to community resources, all of which can enhance motivation, adherence and continuity of rehabilitation behaviors beyond the clinical setting.

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 generalisability 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.

CONCLUSION

As the conclusion, Checkercise® demonstrably enhances long-term physical function and QoL 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.

The Checkercise® board offers a cost-effective solution due to its ease of maintenance compared with other commercially available game-based interventions. It is suitable for stroke rehabilitation across various settings, ranging from inpatient care to outpatient therapy and can serve as a practical therapeutic option for stroke survivors.

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

Ethics statement: Written informed consent was obtained from all participants before study enrollment by the study principal investigator. Participants were informed to withdraw from the study at any time without providing a reason. All personal information was treated as confidential and was securely maintained throughout the study.

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