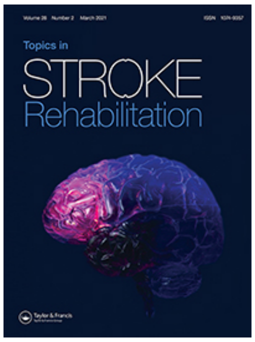

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Ceren Ersoy & Gozde Iyigun

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ARTICLE

Boxing training in patients with stroke causes improvement of upper extremity, balance, and cognitive functions but should it be applied as virtual or real?

Ceren Ersoy and Gozde Iyigun

Department of Physiotherapy and Rehabilitation, Eastern Mediterranean University Faculty of Health Sciences, Famagusta, Turkey

ABSTRACT **Background:** Upper extremity hemiparesis is one of the most common post-stroke disabilities requiring rehabilitation.
Objective: To compare the effects of virtual and real boxing training in addition to neurodevelopmental treatment on the upper extremity, balance, and cognitive functions in hemiparetic stroke patients.
Methods: Forty hemiparetic stroke patients were assigned to either real boxing group-RBG (n=20) or virtual boxing group-VBG (n=20), for a total of 24 sessions (3 sessions/week for 8 weeks). The primary outcome was upper extremity motor ability (Wolf Motor Function Test-WMFT). The secondary outcomes were arm-hand dexterity (Manual Dexterity Test-MMDT), goal-oriented performance (Video Boxing Analysis-VBA), balance functions (Fullerton Advanced Balance Scale-FAB-T), and cognitive functions (Addenbrooke's Cognitive Examination-Revised-ACE-R).
Results: There was small treatment effect on ACE-R, small-medium effect for WFMT and MMDT and large effect on bilateral punching time [VBA (Cohen's d- VBG=0.83; RBG=0.95)] and balance [FAB-T (Cohen's d - VBG=0.89; RBG=0.82)] after treatment in both groups. No significant differences were found for training effects between the groups for upper extremity functions [WMFT (p=0.799; Cohen's d=-0.07), MMDT-PT (p=0.327; Cohen's d=-0.10), MMDT-THTPT (p=0.779; Cohen's d=-0.17) and VBA bilateral punch number (p=0.068; Cohen's d=0.15)], balance functions [FAB-T (p=0.602; Cohen's d=-0.19)] and cognitive functions [ACE-R total (p=0.947, Cohen's d=0.09)].
Conclusion: The study showed that virtual and real boxing training methods, in addition to neurodevelopmental treatment, are effective in improving upper extremity, balance, and cognitive functions in patients with hemiparetic stroke. The training effects were higher on bilateral punching time and balance functions for both groups. There was no superiority of either approach.

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Stroke; virtual reality; boxing; upper extremity functions; cognitive functions; postural balance

Introduction

The World Health Organization's (WHO) definition of stroke is 'a clinical syndrome characterized by rapidly developing clinical signs of focal (or global) disturbance of cerebral function lasting more than 24 hours or leading to death with no apparent cause other than a vascular origin'.[1] The high incidence and mortality of stroke, despite progress over time, affects a large proportion of the population. Therefore, it is a significant health problem. The most common presentation of a stroke patient requiring rehabilitation is contralateral hemiparesis or hemiplegia. Upper extremity dysfunction occurs in approximately two-thirds of patients post-stroke.[2,3] The recovery of upper extremity functions is often slower than the functional recovery of the lower extremity.[4] Only 5% to 20% of stroke patients demonstrate complete functional recovery at six months after stroke, while the majority of patients require constant care from family or social services.[2,5] Therefore, upper extremity dysfunction is one of the most common conditions requiring rehabilitation after stroke.

Restoration of upper extremity functions is critical for performing the activities of daily living autonomously to maintain one's functional independence. Although current evidence indicates that the functional recovery from stroke is positively influenced by goal-specific training or everyday use of the upper extremity.[6] Traditional approaches that require simple and repetitive movements may cause monotony and boredom, and also may lower the patient's motivation to complete the intervention.[7] Many rehabilitation techniques are focusing on the upper extremity motor functions such as muscle strengthening exercises, constraint-induced movement therapy

CONTACT Gozde Iyigun gozde.iyigun@emu.edu.tr Department of Physiotherapy and Rehabilitation, Eastern Mediterranean University Faculty of Health Sciences, Famagusta, Turkey

(CIMT), mirror therapy, mental practice, neuromuscular electrical stimulation, bilateral training, robot-assisted therapy for the paretic upper extremity, virtual reality and neurodevelopmental training (NDT).

The Bobath (NDT) concept is one of the most widely used approaches by clinicians in neurorehabilitation. However, the recent systematic review by Diaz-Arribas et al.[8] highlighted that there is no evidence for the superiority of Bobath concept than other approaches used in post-stroke rehabilitation, especially on improving mobility, lower extremity motor control, gait and activities of daily living. The greater effectiveness of different methods, incorporating overuse of the affected upper extremity via intensive treatments with high-repetitions with or without robotic aids in the motor control of the upper extremity and dexterity, was emphasized in the study.[8] Accordingly, the multiple systematic review study by Hatem et al. suggested that functional bimanual intensive training without constraint (as in CIMT) could be a future pathway for adult stroke neurorehabilitation research and instead of task-specific exercises the use of rehabilitation technology may offer more chances to the nervous system to experience "real" and repetitive activity training of upper extremity.[6]

The use of computer systems has currently become a highly accepted approach in neurorehabilitation.[9,10] Virtual reality (VR) is frequently used in different disease groups at the clinic for rehabilitation purposes.[11] Xbox Kinect, Nintendo Wii, Sony PlayStation, and Cyber Glove are among the most commonly used VR applications in rehabilitation.[12] Exercises may be individualized to suit individual needs by using various VR equipment (i.e., sensors, balance boards, controllers, etc.), which may stimulate neural plasticity according to motor learning principles with repetitive activities. Several studies reported that VR applications improved both upper and lower extremity functions and promoted independence in performing activities of daily living.[13–16] The studies which specifically used the boxing in the Nintendo Wii Fit and Xbox Kinect gaming systems for training stroke patients showed that virtual boxing has a positive effect on improving upper extremity functions and maintaining posture for stroke patients.[7,17]

In recent years, it has been observed that boxing therapy has positive outcomes in individuals with neurological diseases (i.e., Parkinson's disease and stroke).'[1819] In the literature, the first study, including boxing therapy, was conducted by Combs et al. in patients with Parkinson's disease, which concluded that boxing therapy was feasible and reliable for Parkinson's patients.[18] The other preliminary study by Park et al., the effects sitting boxing program in stroke patients investigated and demonstrated that the sitting boxing program had positive impact on upper extremity function, balance, gait, and quality of life in stroke patients.[19] We believe that boxing therapy would be more effective when it is used in a standing position which would be more challenging for especially achieving trunk stabilization and lower extremity movements, however, despite the rising interest in boxing therapy, the effects of boxing therapy in a standing position in stroke patients have not been studied yet. Additionally, they pointed out that a more realistic setting by the use of hitting mitts and sandbag and not virtual reality settings, may generate greater interest among the patients and increase their participation and motivation.[19] However, they only focused on real settings and did not use a virtual environment to compare a more effective boxing therapy method.

This study was designed to understand the effect of real boxing training specifically in standing position targeted toward the improvement of upper extremity functions, balance functions, and cognitive functions compared to virtual boxing training in addition to neurodevelopmental treatment approaches in hemiparetic stroke patients. The study is based on the primary hypothesis (1) that patients who are receiving real boxing training in addition to NDT would demonstrate improvement in upper extremity functions, balance functions, and cognitive functions compared to the patients who are receiving virtual boxing training in addition to NDT. The second hypothesis (2) was that the patients in the real boxing training group will show improvement in upper extremity functions, balance functions, and cognitive functions after the treatment and the third hypothesis (3) was that the patients in the virtual boxing training group will show improvement in upper extremity functions, balance functions, and cognitive functions after the treatment.

Methods

Study design

The study was approved by the Board of Scientific Research and Publications of Eastern Mediterranean University by the decision numbered 2018/02(a)-08. This study was registered at ClinicalTrials.gov (NCT03651479). Forty hemiparetic individuals were randomly assigned to either real boxing group- or virtual boxing group using allocation concealment. Simple randomization was done according to the enrollment order, thus, the participants with odd registration numbers were assigned to VBG, and those with even registration numbers were assigned to RBG. The study protocol through the trial is presented in Figure 1.

Participants

Patients diagnosed with stroke were initially identified from the hospital records, and the local community and consenting patients were screened between September – October 2018 for eligibility. The inclusion criteria for participating in our study were as follows: patients diagnosed as first time ever stroke, hemiparetic, between the ages of 18 and 70, Mini-Mental Test scores ≥23, functional level <4 according to the Modified Rankin Scale, active shoulder flexion ≥90 degrees, and upper extremity spasticity <3 on the Modified Ashworth Scale. Individuals were excluded from the study if they had any of the following criteria: uncontrolled hypertension, cardiac diseases, visual impairment, subluxation and fracture in the shoulder, limitation in passive normal joint movement on the hemiplegic side, as it will prevent them from performing successful punching movement, and botulinum toxin administration or surgical operation in the last 6 months.

The sample size was calculated by using the G* Power 3.1.9.2 program. The mean and standard deviation values were taken as a reference from the study of Jo et al.[20] Statistical power analysis calculations suggested 15 subjects for each group ($\alpha = 0.05$, 95% confidence interval), but considering dropouts, the number was increased by 33%, and finally, 40 individuals were planned to be included. Therefore, based on the power calculation, 20 subjects were enrolled in each group; real boxing group- RBG (n = 20) or virtual boxing group- VBG (n = 20)A total of 78 patients were screened, among which 40 patients met the inclusion criteria and underwent randomization, as shown in the CONSORT flow diagram (Figure 1). Written informed consent was obtained from the volunteers prior to participation. The first participant of the current study was enrolled on 10 November 2018.

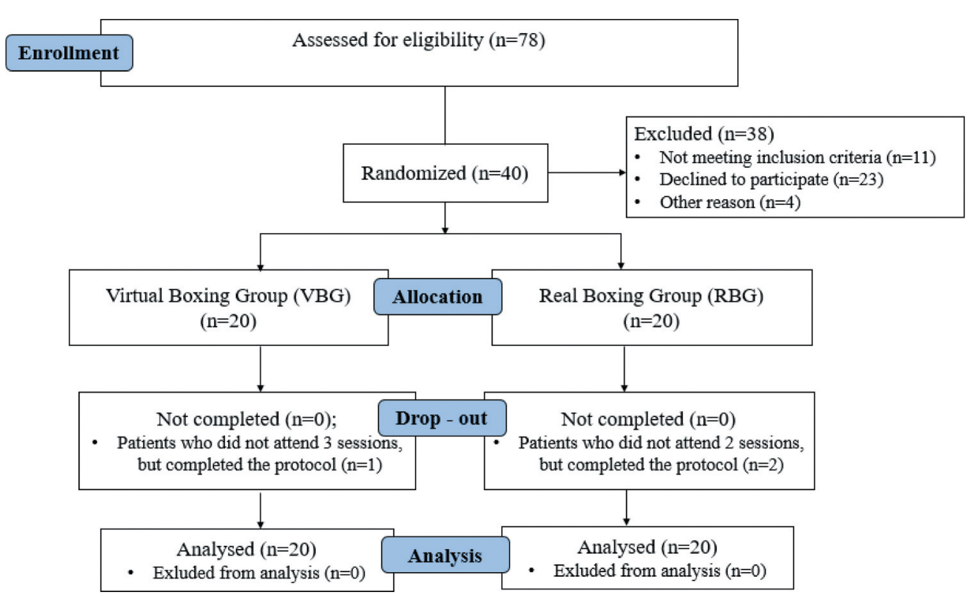

Figure 1. Study protocol (CONSORT diagram).

Study procedures

The Bobath approach is a problem-solving-based neurodevelopmental (NDT) approach, which is based on neuroplasticity theories.[21,22] The NDT treatment protocol consisted of upper extremity facilitation techniques and activities by the patient's functional level involving mat exercises, weight shifting training, trunk control, balance activities, and gait training. The NDT treatment programs were planned according to the patient's functional level, individual requirements, and expectations of the patients, however, the handling techniques and the number of sets and repetitions were standardized for both groups. In both groups, the NDT approach was administered for a total of 24 sessions (8 weeks, 3 sessions/week, 30 minutes/day). To improve the upper extremity functions and to increase the rhythm, timing, and sequencing abilities of the patients' two different boxing protocols were added to the NDT program. Therefore, the patients received either virtual boxing training for 24 sessions (8 weeks, 3 sessions/week, 30 minutes/day) in VBG or real boxing training for 24 sessions (8 weeks, 3 sessions/week, 30 minutes/day) in RBG, in addition to the NDT protocol. Therefore, the total duration of the session was 1 hour, 30 minutes of NDT, and 30 minutes of virtual or real boxing training. All the treatment protocols were applied in a clinical setting by the same physiotherapist.

Intervention

Boxing therapy appears to be a new training approach in rehabilitation settings with positive results. Boxing training requires trunk stabilization, trunk rotation, postural adjustments (i.e., dynamic change of weight transfer), bilateral upper extremity movement, and coordinated lower extremity movements in multiple directions. Remembering the sequence of boxing actions requires a rapid selection of complex motor programs for mobility which also involves the incorporation of cognitive functions like executive functions and attention skills.[18,23–25] Boxing training may provide practice for both motor functions (i.e., bilateral upper extremity training, trunk stabilization, and weight shifting in standing) and cognitive functions for stroke patients. Therefore, boxing training may be an effective alternative for improving function in patients with stroke.

Virtual boxing

Virtual reality and gaming have emerged as new treatment approaches in stroke rehabilitation. They have some advantages over traditional therapy approaches with the opportunity to practice everyday activities that are not or cannot be practiced within the clinical environment. Virtual reality programs are designed to be more interesting and enjoyable than traditional therapy methods that might mean that they are encouraging higher numbers of repetitions, which is important for motor learning.[26]

The Xbox Kinect 360 game console was used for the virtual boxing training in this study. The Xbox Kinect infrared sensor allows the user to easily detect movements and monitor movements in real-time via their avatar on the screen. The user does not need to use any remote control, and therefore, patients with reduced fine motor skills can use this game console more effectively.[7] The Microsoft Xbox Kinect 360 gaming system has three main components: The Kinect Sensor, which senses the patient's body to detect their movements, the Xbox 360 Game Console, a device that runs a variety of game programs, and a screen. The Xbox Kinect game console and sensor were placed in a private room to ensure that the patients were not affected by external factors. The patient's position was determined at a distance of 2.25–2.75 meters from the screen, and the camera sensor was adjusted on the console to detect the patient's body movements. For the treatment, the Boxing Game was used from among Kinect Sports games, which provided bilateral use of the upper extremity and combined use of the lower and upper extremities of the hemiparetic side.

The Boxing Game included 3 different positions: direct punch (high and low), hook (punch against the opponent's ear), and block position (high and low). As the player's success increased (the number of rounds increased), the speed at which the opposing avatar reacted to the punches increased. The treatment program took 5 minutes (4 minutes of playing and 1 minute of resting), and the level of

a. Real boxing training   b. Virtual boxing training

Figure 2. Real and virtual boxing training.

difficulty changed from level 1 to 4 according to the performance of the patients. Precautions were taken against possible complications during the game (Figure 2).

Real boxing

In the real boxing group, the training was planned according to the virtual boxing group, and the training time and movements in both boxing groups were similar. In the real boxing training group, the physiotherapist and the patient were wearing boxing mitts, and the patients were given instructions to punch the physiotherapist's mitt by a pre-specified treatment protocol. The real boxing program, which was designed in similarity to the virtual boxing training, consisted of 4 levels. Level 1 included unilateral jab/direct punch (high and low). Level 2 included bilateral jab/direct and hook/hook punches (high and low). Level 3 included bilateral direct punches/jab combinations (right jab + left jab) (high and low). Level 4 included bilateral punch combinations either combinations of different punching styles (i.e. jab + cross) or different side (right + left) (high and low). The resistance and frequencies between the levels were increased by the physiotherapist as the session progressed (Figure 2).

Outcome measures

The socio-demographic [age, sex, body mass index, and dominant side] and disease-related [time since stroke and side of hemiparesis] characteristics of the participants were recorded. The primary outcome of the study was Wolf Motor Function Test (WMFT), and the secondary outcomes were the following measurement tools; Minnesota Manual Dexterity Test (MMDT), Video Boxing Analysis (VBA), Fullerton Advanced Balance (FAB) and Addenbrooke's Cognitive Assessment (ACE-R). The measurements were taken at the baseline (0 weeks) and on completion of the treatment (8 weeks).

Upper extremity functions

Wolf Motor Function Test (WMFT)

WMFT quantifies upper extremity motor ability through the use of timed and functional tasks. The original version of WMFT was developed by Wolf et al. in 1989 to examine patients with moderate to severe upper extremity motor deficits.[27] Then, the modified version of the test was developed by Taub et al. to assess the motor abilities of chronic patients who had suffered mild to moderate stroke.[28] The widely used version of WMFT consists of 17 items, items 7 and 14 are related to subject strength, and the other 15 are related to subject functional ability during various tasks. Performances are scored using a 6-point functional ability scale, and the less affected upper extremity is followed by the most affected side. The total score also referred to as the Functional Ability score (WMFT-FAS), is the sum of the scores of 15 items (with a 6-point ordinal score from 0 to 5). The maximum total score is "75", lower scores indicating lower functional levels.[29] The WMFT has good reliability for total functional score (interrater, ICC = 0.93–0.99 and test-retest, ICC = 0.97) and adequate criterion validity with Upper Extremity Fugl-Meyer Assessment (r = −0.57 – −0.88) in people with stroke.[27,29,30]

Minnesota Manual Dexterity Test (MMDT)

MMDT measures the speed of gross arm and hand movements (arm-hand dexterity) during rapid eye-hand coordination tasks. The MMDT material consists of a plastic collapsible board with 60 holes and 60 cylindrical blocks (3.7 cm in diameter and 1.9 cm in height). MMDT involves five subtests: Placing Test, Turning Test, Displacing Test, One-Hand Turning and Placing Test, and Two-Hand Turning and Placing Test. The Placing Test (1st item: taking blocks with one hand and putting them in the holes on the board in a standardized order) and Two-Hand Turning and Placing Test (5th item: taking blocks with two hands and putting them in the holes on the board in a standardized order) were the two items selected for this study. The participants were given a 15-second trial for both items. The test was timed with a stopwatch, and each item was measured three times. The number of seconds it took to complete the task on each of the trials was recorded. An average score from the three trials was calculated. The lower the score, the better the outcome.[31,32] Although it was stated that the MMDT measures the alterations of the upper limb function throughout time and can also be useful in scientific approaches to quantify the performance during treatment in people with stroke, the psychometric properties are still not demonstrated.[33]

Video Boxing Analysis (VBA)

The VBA evaluation method was used to evaluate the goal-oriented performance and endurance analysis of the upper extremity. For boxing analysis, the patients were videotaped while punching with their right side, punching with their left side, and punching bilaterally. Then, the videotapes were watched for analysis, and the number of right unilateral punches in30 second, number of left unilateral punches in30 second, and number of bilateral punches in 30 second were recorded. These analyzes were conducted for a quantitative assessment of the number of punches per 30 second. This measurement method was created and constructed by the authors of this study. The higher number of punches indicates a better outcome of this analysis.

Balance assessment

Fullerton Advanced Balance (FAB) scale

The FAB scale is a performance-based scale that was developed to evaluate changes in many aspects of balance.[34] The FAB scale consists of 10 test items for the evaluation of static and dynamic balance status. These test items are; 1. Feet together, eyes closed, 2. Reach forward to retrieve an object, 3. Turn in a full circle, 4. Step up and over a bench, 5. Tandem walk, 6. Stand on one leg, 7. Stand on foam, eyes closed, 8. Two-footed jump, 9. Walk with head turns, 10. Reactive postural control. Each test item is scored using a 0–4 scale. The highest score indicating better balance abilities is "40" points, and the lowest is "0". The FAB-T (Fullerton Advanced Balance – Turkish) scale was found to be a reliable and valid measurement of balance in the Turkish elderly population.[35]

Cognitive assessment

Addenbrooke's Cognitive Assessment – Revised (ACE-R)

ACE-R is sensitive in the differential diagnosis of early-stage dementia.[36] However, its design and psychometric properties are also suitable to provide information about cognitive functions and cognitive deficits in patients without dementia after a stroke.[37] ACE-R consists of five domains, including attention/orientation, memory, verbal fluency, language, and visuospatial ability.[38] The ACE-R total scale score ranges from 0 to 100. The ACE-R subscale scores range between; 0–18 points for attention, 0–26 for memory, 0–14 for fluency, 0–26 for language, and 0–16 for visuospatial processing. Higher scores indicate better cognitive functioning. ACE- R scale was found as reliable and valid in the Turkish population.[39] The ACE-R has high internal reliability (Cronbachs a =.82), and the five cognitive domains from the ACE-R ranged were; attention and orientation a = .53, memory a = .41, fluency a = .44, language a = .64, and visuospatial a = .60.[40] The total ACE-R score sensitivity and specificity reached a maximum value of 86.5 points (sensitivity 0.82, specificity 0.46).[37]

Statistical analysis

The statistical analysis was carried out using the statistical package SPSS version 24.0. The variables are reported by percentage (%) and mean±standard deviation (x± sd). Shapiro-Wilk test was used to determine whether the data had a normal distribution. Pearson's Chi-Squared Test and Fisher's Exact Test were used for comparison of the categorical data between the groups. Mann-Whitney U test was used to analyze the intergroup differences, and Wilcoxon Signed-Rank Test was used to analyze the intragroup differences. $P < .05$ was accepted as a statistically significant level. The arithmetic means are presented with a 95% confidence interval (95% CI) with lower and upper limit values. Both "p" values and 95% CI values were considered while interpreting the differences between the groups. To analyze the intergroup changes, effect sizes were calculated with "Cohen's d". The effect sizes were interpreted as a small effect (d ≥ 0.2), medium effect (d ≥ 0.5), and large effect (d ≥ 0.8).[41] The mean difference (MD) was also calculated to evaluate the change from the baseline to post-treatment as a mean change ± standard deviation.

Results

Participants

Table 1 shows the distribution of the participants based on their socio-demographic and clinical characteristics. There was no significant difference between VBG and RBG for their socio-demographic (age, sex, dominant extremity) and clinical (time since stroke, shoulder pain) characteristics before the treatment (p > .05). However, there were more right hemiparetic patients in VBG (70%) and more left hemiparetic patients in RBG (65%).

Table 1. Socio – demographic and clinical characteristics of the participants.

	VBG (n = 20)		RBG (n = 20)		
	n	%	n	%	p- value
Age (years)					
55 years ≥	7	35	5	25	0.717[a]
56— 65 years	8	40	8	40	
66 years ≤	5	25	7	35	
Mean ± SD	58.25 ± 11.19		60.15 ± 10.19		0.588[b]
Sex					
Female	8	40	5	25	0.311 [c]
Male	12	60	15	75	
Time since stroke (months)					
12 months≥	5	25	3	15	0.675 [c]
13— 35 months	9	45	9	45	
36 months≤	6	30	8	40	
Mean ± SD	31.10 ± 27.63		36.35 ± 26.00		0.409[b]
Affected extremity					
Right	14	70	7	35	0.027 [c]
Left	6	30	13	65	
Dominant extremity					
Right	18	90	18	90	0.698[a]
Left	2	10	2	10	
Shoulder pain					
Yes	12	60	9	45	0.342 [c]
No	8	40	11	55	

Values are mean ± SD. p value significance = ≥ 0.05. N:sample size. VBG: Virtual Boxing Group; RBG: Real Boxing Group; [a]: Fisher exact chi – square test; [b]: Mann – Whitney U Test [c]: Pearson chi square test;

Findings related to upper extremity functions

There was a significant improvement on the WMFT for both groups after the treatment; within-group differences was as follows; VBG (MD = 0.90, 95% CI, −5.19 — 6.99; p = .004; Cohen's d = 0.09) and RBG (MD = 1.40, 95% CI, −0.42—3.22, p = .000; Cohen's d = 0.30). The minimal clinically significant change (MCID) for the WMFT-FAS has been established as 0.2–0.4 points on the for chronic stroke survivors.[42] The WMFT results in our study (0.90 points VBG and 1.40 points RBG) are greater than the previously specified MCID values. Therefore, the scores may represent a clinically meaningful improvement. However, the between-group differences for WFMT were not statistically significant (p = .799; Cohen's d = −0.07).

Likewise, the MMDT scores of both groups were significantly higher after the treatment: MMDT-Placing test (MD = −0.11, 95% CI, −0.43—0.21; p = .017; Cohen's d = −0.21) and MMDT-Two hand turning and placing test (MD = −0.43, 95% CI, −1.61—0.75; p = .000; Cohen's d = −0.09) scores for the VBG and MMDT-Placing test (MD = −0.05, 95% CI, −0.37—0.27; p = .000; Cohen's d = −0.23) and MMDT-Two hand turning and placing test (MD = −0.09, 95% CI, −0.60—0.42; p = .000; Cohen's d = −0.11) for the RBG. However, there was no significant difference between the groups for MMDT-Placing test (p = .327; Cohen's d = −0.10) and MMDT-Two hand turning and placing test (p = .779; Cohen's d = −0.17).

The Video Boxing Analysis (VBA) results showed a significant improvement after the treatment for the right punch (MD = 2.90, 95% CI, −1.69—7.49; p = .007; Cohen's d = 0.40), left punch (MD = 3.20, 95% CI, −1.70—8.10; p = .003; Cohen's d = 0.41) and bilateral punch (MD = 7.80, 95% CI, 2.21—13.39; p = .000; Cohen's d = 0.89) scores in the VBG and the right punch (MD = 2.35, 95% CI, −4.32—9.02; p = .002; Cohen's d = 0.22), left punch (MD = 3.10, 95% CI, −2.57—8.77; p = .000; Cohen's d = 0.35) and bilateral punch (MD = 6.65, 95% CI, 1.47—11.82; p = .000; Cohen's d = 0.82) scores in the RBG. There was a large intragroup effect sizes for bilateral punching in both groups (VBG; Cohen's d = 0.89 and RBG; Cohen's d = 0.82). There was no significant difference between the two treatment protocols for any VBA scores [left punch (p = .779; Cohen's d = 0.01), right punch (p = 1.000; Cohen's d = 0.06) and bilateral punch (p = .068; Cohen's d = 0.15)].

There was an improvement in both groups after the treatment, however, when comparing the effects of both boxing training methods on upper extremity functions the intervention effect was similar (Table 2).

Findings related to balance functions

The mean difference from the baseline to post-treatment on the Fullerton Advanced Balance Scale (FAB-T) scores was significantly higher in both groups; VBG (MD = 4.00, 95% CI, 0.94—7.05; p = .000; Cohen's d = 0.83) and RBG (MD = 4.95, 95% CI, 1.61—8.28; p = .000; Cohen's d = 0.95) and. Both groups demonstrated significant improvements with large intragroup effect sizes on balance functions (VBG; Cohen's d = 0.83 and RBG; Cohen's d = 0.95). However, the difference between VBG and RBG was not statistically significant (p = .602; Cohen's d = −0.19) (Table 2).

Findings related to cognitive functions

There was an improvement on Addenbrooke's Cognitive Examination- Revised (ACE-R) total scores in both groups; VBG (MD = 1.20, 95% CI, −3.84—6.24; p = .000; Cohen's d = 0.15) and RBG (MD = 0.50, 95% CI, −4.30—5.30; p = .000; Cohen's d = 0.06). There was slight different improvement on the ACE-R sub scores [VBG; ACE-R memory (MD = 1.20, 95% CI, −1.06—3.46; p = .001; Cohen's d = 0.33) and ACE-R fluency (MD = 0.85, 95% CI, −0.34—2.04; p = .007; Cohen's d = 0.45) and RBG; ACE-R fluency (MD = 0.70, 95% CI, −0.05—1.45; p = .000; Cohen's d = 0.15), ACE-R language (MD = 0.35, 95% CI, −0.64—1.34; p = .008; Cohen's d = 0.22) and ACE-R visuospatial (MD = 0.50, 95% CI, −0.43—1.43; p = .015; Cohen's d = 0.34)] after the treatment, however, the difference between groups was not statistically significant. The intervention effect was small to medium for the ACE-R domains and small for ACE-R total (p = .947, Cohen's d = 0.09) (Table 2).

None of the participants reported having any adverse events such as dizziness, falling, over-fatigue or a strike during and/or after any of the boxing training sessions.

Discussion

This randomized controlled study compared the effects of virtual and real boxing training programs on upper extremity functions, balance functions, and cognitive functions in addition to neurodevelopmental treatment (NDT) approaches. The results showed that both the virtual and real boxing training methods were effective for improving upper extremity functions, balance functions, and cognitive functions in addition to NDT. Although both treatment approaches have positive effects regarding upper extremity functions, balance

Table 2. Comparison within and between the two treatment groups (VBG and RBG).

		Before Treatment $\bar{x}$± *sd* (%95 CI)	After Treatment $\bar{x}$± *sd* (%95 CI)	Mean difference (MD) (%95 CI)	p- value[a] (Within group difference)	p- value[b] (Between group difference)	effect size[c] (Within group	effect size[c] (Between group)
WMFT	VBG	68.00 ± 9.46 (63.57—72.43)	68.90 ± 9.57 (64.42—73.38)	0.90 (−5.19—6.99)	0.004	0.799	0.09	−0.07
	RBG	69.65 ± 3.12 (68.19—71.11)	71.05 ± 2.56 (69.85—72.25)	1.40 (−0.42—3.22)	0.000		0.30	
MMDT Placing Test	VBG	1.69 ± 0.59 (1.41—1.96)	1.58 ± 0.40 (1.39—1.77)	−0.11 (−0.43—0.21)	0.017	0.327	−0.21	−0.10
	RBG	1.78 ± 0.50 (1.55—2.01)	1.73 ± 0.51 (1.49—1.97)	−0.05 (−0.37—0.27)	0.000		−0.09	
MMDT Two— hand Turning and Placing Test	VBG	3.39 ± 2.53 (2.20—4.57)	2.96 ± 0.69 (2.63—3.29)	−0.43 (−1.61—0.75)	0.000	0.779	−0.23	−0.17
	RBG	2.51 ± 0.99 (2.05—2.98)	2.42 ± 0.55 (2.16—2.67)	−0.09 (−0.60—0.42)	0.000		−0.11	
VBA Left punch number	VBG	31.50 ± 6.63 (28.4—34.60)	34.70 ± 8.58 (30.68—38.72)	3.20 (−1.70—8.10)	0.003	0.779	0.41	0.01
	RBG	30.80 ± 8.98 (26.6—35.00)	33.90 ± 8.75 (29.81—37.99)	3.10 (−2.57—8.77)	0.000		0.35	
VBA Right punch number	VBG	30.15 ± 6.20 (27.25—33.05)	33.05 ± 8.04 (29.29—36.81)	2.90 (−1.69—7.49)	0.007	1.000	0.40	0.06
	RBG	31.80 ± 10.73 (26.78—36.82)	34.15 ± 10.12 (29.42—38.88)	2.35 (−4.32—9.02)	0.002		0.22	
VBA Bilateral punch number	VBG	37.25 ± 7.54 (33.72—40.78)	45.05 ± 9.78 (40.47—49.63)	7.80 (2.21—13.39)	0.000	0.068	0.89	0.15
	RBG	33.65 ± 7.56 (30.11—37.19)	40.30 ± 8.58 (36.28—44.32)	6.65 (1.47—11.82)	0.000		0.82	
FAB- T	VBG	26.20 ± 4.77 (23.97—28.43)	30.20 ± 4.76 (27.97—32.43)	4.00 (0.94—7.05)	0.000	0.602	0.83	−0.19
	RBG	24.45 ± 5.00 (22.11—26.79)	29.40 ± 5.40 (26.87—31.93)	4.95 (1.61—8.28)	0.000		0.95	
ACE- R Attention	VBG	16.30 ± 1.66 (15.52—17.08)	16.30 ± 1.66 (15.52—17.08)	0.00 (−1.06—1.06)	1.000	0.925	0.00	−0.13
	RBG	16.20 ± 1.24 (15.62—16.78)	16.40 ± 1.50 (15.70—17.10)	0.20 (−0.68—1.08)	0.157		0.14	
ACE- R Memory	VBG	12.25 ± 3.54 (10.59—13.91)	13.45 ± 3.53 (11.80—15.10)	1.20 (−1.06—3.46)	0.001	0.862	0.33	0.26
	RBG	13.50 ± 3.24 (11.99—15.01)	13.80 ± 2.73 (12.52—15.08)	0.30 (−1.61—2.21)	0.206		0.01	
ACE- R Fluency	VBG	7.30 ± 1.84 (6.44—8.16)	8.15 ± 1.90 (7.26—9.04)	0.85 (−0.34—2.04)	0.007	0.820	0.45	0.09
	RBG	7.35 ± 1.18 (6.80— 7.90)	8.05 ± 1.19 (7.49—8.61)	0.70 (−0.05—1.45)	0.002		0.59	
ACE- R Language	VBG	23.05 ± 2.28 (21.98—24.12)	23.45 ± 1.99 (22.52—24.38)	0.40 (−0.96—1.76)	0.071	0.738	0.18	0.02
	RBG	23.40 ± 1.50 (22.70—24.10)	23.75 ± 1.62 (22.99—24.51)	0.35 (−0.64—1.34)	0.008		0.22	
ACE- R Visuospatial	VBG	13.45 ± 1.73 (12.64—14.26)	13.65 ± 1.73 (12.84—14.46)	0.20 (−0.90—1.30)	0.102	0.678	0.11	−0.18
	RBG	13.00 ± 1.56 (12.27—13.73)	13.50 ± 1.36 (12.86—14.14)	0.50 (−0.43—1.43)	0.015		0.34	
ACE- R Total	VBG	72.25 ± 9.07 (68.00—76.50)	73.45 ± 6.49 (70.41—76.49)	1.20 (−3.84—6.24)	0.000	0.947	0.15	0.09
	RBG	75.05 ± 8.47 (71.09—79.01)	75.55 ± 6.39 (72.56—78.54)	0.50 (−4.30—5.30)	0.000		0.06	

VBG: Virtual Boxing Group; RBG: Real Boxing Group; WMFT: Wolf Motor Function Test; MMDT: Minnesota Manual Dexterity Test; PT: Placing Test; THTPT: Two – hand Turning and Placing Test; VBA: Video Boxing Analysis; LPN: Left Punch Number; RPN: Right Punch Number; BPN: Bilateral Punch Number; ACE- R: Addenbrooke's Cognitive Examination- Revised; FAB-T: Fullerton Advanced Balance Scale; Before treatment: Outcome assessment data prior to intervention initiation; After treatment: Outcome assessment data after 8-week intervention; [a]: *p*-value of Wilcoxon Sign Test; [b]: *p*-value of Mann-Whitney U Test; [c]: Cohen's d value

functions, and cognitive functions, there was no significant superiority of one training method over the other. Furthermore, considering the training effects, it was found that the intragroup effect sizes were large on bilateral punching time and balance functions for both boxing training methods. This implies that the boxing treatment, no matter real or virtual, could have a significant effect on balance and bilateral upper limb movement time. The improvements in upper extremity functions, balance functions, and cognitive functions in both groups after treatment are attributed to the boxing training programs as well as to the effectiveness of NDT.

A unique characteristic of the Kinect is that the games are played without the use of a controller as entire extremity movements are monitored by 3D depth cameras, unlike in the case of other VR games. In this sense, it provides a great advantage for patients with insufficient grip strength. Another advantage is that the Xbox Kinect can allow high-repetition movement practice, which may eventually produce lasting changes in motor system networks, motor learning, and motor function. Studies designed to investigate motor learning in humans indicated the importance of large amounts of practice ranging between 300 and 800 repetitions per session.[43,44] In a randomized controlled trial by Sin and Lee, subacute stroke patients were allocated either to virtual reality training using Xbox Kinect and conventional occupational therapy or to conventional occupational therapy alone. For training, they used Xbox Kinect programs such as Boxing and Bowling in the Kinect sports and adventure pack, and all programs required the use of the upper extremities. It was stated that the hemiplegic stroke survivors who received additional virtual reality training showed more improvements in their upper extremity motor function and gross manual dexterity. However, the effects of virtual reality training may have been a result of the greater total intervention time in the training group in comparison to the control group.[7] Thus, the potential efficacy of Xbox Kinect in the rehabilitation of post-stroke survivors needs to be investigated in greater depth.

To our knowledge, there is only one study in the literature investigating the effects of real boxing training in chronic stroke patients.[19] In a previous study by Park et al., the boxing group underwent a sitting boxing program (3 times/week) as well as conventional physical therapy (3 times/week) for 6 weeks. The upper extremity ability in the conventional physical therapy group also improved; however, this improvement was lower than that noted in the boxing program group, which was believed to be due to the NDT and PNF interventions. The results of these studies showed that regardless of the exercise method applied, the active participation of patients to the treatment is beneficial in improving upper extremity functions. In this study, instead of using virtual reality settings, an actual boxing program involving hitting mitts and a sandbag was preferred to be used to achieve a more realistic setting, generate greater interest, and increase the participation and motivation of the participants.[19]

The upper extremity functions were measured with three different outcomes to investigate the different aspects, and small-medium treatment effects were found in the upper extremity motor ability and dexterity results and large treatment effects for bilateral punching which was used to evaluate the goal-oriented performance and endurance analysis of the upper extremity both groups after the treatment. In this sense, we assume that boxing training, no matter virtual or real, ensures improvement of upper extremity functions by promoting the active use of the hemiparetic upper extremity. This was compatible with the systematic of Diaz-Arribas et al[8], highlighting the effects of repeated use of the affected upper extremity by using an intensive treatment with high-repetitions.,The effects of rehabilitation settings (i.e., using hitting mitts or virtual environment) used in the boxing training may change the results because they use different feedback systems. This was not within the scope of this study but presumably, more tactile feedback used in the real boxing, whereas more auditory and visual feedback used in the virtual boxing although there was no significant difference between the real and virtual boxing groups.

Waller et al. demonstrated that postural control improved following hemiparetic arm training intervention performed in a standing position without explicit postural control instructions, emphasizing the possible role of implicit learning.[45] Implicit engagement is essential for the integration of different mechanical, sensory, motor, and goal-oriented systems that contribute to arm function and postural regulation. On the other side, using explicit cues for both arm movements and trunk control would constitute a dual-task situation that individuals with stroke would find quite difficult.[45] Therefore, without raising awareness of dual-tasking, activation of lower extremities and trunk muscles may influence the activity of the upper extremities.[46] An example of this could be punching, which is a complex motion involving movements of the upper extremity, trunk, and lower extremity.[47] Filimonov et al., in one of the earliest studies, identified three different components of punching in boxing: 1) extension movement of the upper extremity; 2) rotational movement of the trunk and 3) extension movement of the lower extremity.[48] It should be noted that one of the main focuses in boxing training should be trunk rotation, which is essential to generate powerful punches and transform vertical ground reaction force into horizontal punch force,[49] which might contribute to the improvement of anticipatory postural control, transferring the center of pressure (COP) and weight shifting ability through the paretic side.

In our study, both boxing training methods were found to be effective in the improvement of balance functions, and the effect sizes were large for each group. The improvement of balance functions in both groups may be due to the increased strength of the trunk muscles by using rotational movements of the trunk frequently during boxing training and increased weight transfer to the paretic lower extremity. Similar to our study, the study of Park et al. using real boxing training demonstrated balance score improvements after sitting boxing training.[19] Xbox Kinect is the optimal VR device for patients with good dynamic postural balance and promotes active use of lower extremity and trunk movements, unlike other game consoles that require upper extremity movement. However, to our knowledge, no study investigated the effects of Xbox Kinect boxing training on balance functions. It is known that to achieve successful balance rehabilitation, it is important to include goal-oriented activities, ensure the active participation of the patient, and provide intensive repetitive training. Accordingly, both boxing training methods seemed to include targeted activities that increase the patient's active participation.

The emergence of providing intensive repetitive training under changing environmental conditions and ensuring the active participation of the patient are important principles of motor learning. It is important to differentiate the effects of training in different environmental conditions for stroke patients. To the best of our knowledge, this is the first study to compare "virtual" and "real" environments. There was a small-medium positive effect of both boxing training methods on cognitive functions. There was a tendency for higher improvement for memory in VBG, whereas fluency, language, and visuospatial in RBG improved more, while the difference was statistically insignificant. We believe that more explicit learning was provided in the real boxing training, and more implicit learning strategies were used in the virtual boxing training. Although these methods affect the cognitive domains differently, it may be assumed that motor learning may be achieved through both explicit and implicit learning, and apparently, both boxing training methods contributed similarly.

The second and third hypothesis of this study questioning whether the patients in the real boxing training group and virtual boxing training group will show improvement in upper extremity functions, balance functions, and cognitive functions after the treatment resulted positively. Indicating that both of the boxing training methods in addition to NDT were effective for improving upper extremity functions, balance functions, and cognitive functions without any negative or harmful effects (i.e. falling or over-fatigue). However, the treatment effects were small-medium for most of the parameters. There were large effects on bilateral punching and balance functions. Punching movement used in the boxing training requires the control of upper extremity, trunk, and lower extremity and it is not only promoting the active and repeated use of the hemiparetic upper extremity but also promoting rotational movements of the trunk and transferring the body weight to the paretic lower extremity. The first hypothesis of the study comparing the effects of real and virtual boxing addition to the NDT indicated no difference in any of the parameters between the two boxing training methods. The answer to the question about whether boxing training should be applied as virtual or real is that boxing training can be applied both as virtual and real.

Study Limitations Although the findings of this study were encouraging, some limitations should be noted. The primary limitation was the patient population. The participants had to stand independently and be able to perform upper extremity movements actively to safely achieve both boxing training methods. Therefore, the results of this study may not be generalized to all stroke patients (i.e., those who are not ambulatory and those who are not able to use their hemiparetic upper extremity) and may only be generalized to patients who have higher functional levels. Lack of an equal number of right and left hemiparetic patients in VBG and RBG are also among the limitations of the study, which was due to the randomization process. Lack of an equal number of right and left hemiparetic patients in VBG and RBG are also among the limitations of the study, which was due to the randomization process. In the VBG, the percentage of the right hemiparetic individuals were 70%, whereas 35% of the individuals were right hemiparetic in the RBG. The difference between the sides of the hemiparesis in two groups was found to be statistically significant. The side of the lesion post-stroke may affect the recovery of an independent stance with an advantage of the patients with right hemiparesis. However, previous studies reveal no significant difference in terms of balance functions. In the study of Laufer et al.[50] investigating the effects of the side of brain lesion on the recovery of functional abilities and balance control among subjects 2 months post-stroke, no difference was found in functional ability and balance control between left and right hemiparetic patients who achieved independent standing at the end of the first month poststroke. Similarly in a previous study by Yatar-Iyigun et al.,[51] examining the relationship between falling frequency, fear of falling, balance functions, balance security and hemiparetic side in patients with stroke, found higher fear of falling and lower balance confidence level in left hemiparetic patients comparing to right hemiparetics. However, no difference was found in falling frequency and balance functions between right and left hemiparetic patients.

Another important limitation of our study was the lack of a control group, receiving only NDT. The fact that a control group who received only NDT was not included in our study poses difficulty in interpreting whether the improvement in the parameters mentioned above was due to NDT treatment or boxing treatment. But the purpose of our study was not to investigate the effectiveness of NDT treatment but rather to compare the effects of real and virtual boxing therapy. Including only NDT group might create inequality in terms of the amount of treatment.Another limitation was the device utilized in our study. We preferred to use Xbox Kinect due to its unique characteristic that users do not need to use any remote control. However, the system has limitations in rehabilitation settings; the time spent in calibrating the Xbox Kinect device before each treatment during virtual boxing training was time-consuming, and problems caused by the use of technology occurred during treatment (i.e. freezing of the image during the game and delays of the treatment) which may cause both the clinician and the patient to have difficulties. Additionally, physiotherapists need to provide various feedback to ensure that the patient is in the right pattern. Possible dangerous situations such as falling or dizziness with the use of this technology may cause problems for home use. Therefore, the availability of technology-assisted methods without a physiotherapist should be questioned.

Although there are studies on virtual reality methods in the literature, very few studies on real boxing training are available. Future studies may examine the effects of real boxing training in patients at different stages of stroke (acute, subacute, and chronic). We have determined that virtual and real boxing training, which is different from traditional physiotherapy methods, increases the motivation and performance of patients. It is necessary to evaluate the motivation and performance of participants with objective methods and to assess engagement and adherence to therapies in future studies

Conclusions

This study comparing the effects of virtual and real boxing training in addition to neurodevelopmental treatment on the upper extremity, balance, and cognitive functions in addition to neurodevelopmental treatment approach in hemiparetic stroke patients has shown both training methods were effective for improving upper extremity functions, balance functions, and cognitive functions. Despite these differences, the results of this present study revealed no evidence of the superiority of either approach. Considering the training effects, both boxing training methods had a greater impact on bilateral punching time and balance functions. We believe that in addition to the neurodevelopmental treatment approach both boxing training methods may be used effectively and safely to improve the upper extremity functions, balance functions, and cognitive functions of hemiparetic stroke patients who are bored of traditional rehabilitation methods.

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ORCID

Ceren Ersoy http://orcid.org/0000-0001-8407-2287
Gozde Iyigun http://orcid.org/0000-0001-8346-9952

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