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Yao-Jen Chang
Chung Yuan Christian University

Ching-Yi Wu
Chang Gung University

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ORIGINAL ARTICLE

Comparison of Kinect2Scratch game-based training and therapist-based training for the improvement of upper extremity functions of patients with chronic stroke: a randomized controlled single-blinded trial

Jen-Wen HUNG [1, 2] *, Chiung-Xia CHOU [1], Yao-Jen CHANG [3], Ching-Yi WU [4, 5, 6], Ku-Chou CHANG [7, 8], Wen-Chi WU [1], Stephen HOWELL [9]

[1]Department of Rehabilitation, Kaohsiung Medical Center, Chang Gung Memorial Hospital, Kaohsiung, Taiwan; [2]School of Physical Therapy, College of Medicine, Chang Gung University, Taoyuan, Taiwan; [3]Department of Electronic Engineering, Chung Yuan Christian University, Chung-Li, Taiwan; [4]Department of Occupational Therapy, Graduate Institute of Behavioral Sciences, College of Medicine, Chang Gung University, Taoyuan, Taiwan; [5]Healthy Aging Research Center, Chang Gung University, Taoyuan, Taiwan; [6]Department of Physical Medicine and Rehabilitation, Chang Gung Memorial Hospital, Taoyuan, Taiwan; [7]Division of Cerebrovascular Diseases, Department of Neurology, Kaohsiung Chang Gung Memorial Hospital, Kaohsiung, Taiwan; [8]Department of Neurology, College of Medicine, Chang Gung University, Taoyuan, Taiwan; [9]SMARTlab, University College Dublin, Dublin, Ireland

*Corresponding author: Jen-Wen Hung, No.123, Ta-Pei Road, Niao-Sung District, Kaohsiung City 833, Taiwan. E-mail: hung0702@cgmh.org.tw

ABSTRACT

BACKGROUND: Virtual reality and interactive video games could decrease the demands on the time of the therapists. However, the cost of a virtual reality system and the requirement for technical support limits the availability of these systems. Commercial exergames are not specifically designed for therapeutic use, most patients with hemiplegic stroke are either too weak to play the games or develop undesirable compensatory movements.

AIM: To develop Kinect2Scratch games and compare the effects of training with therapist-based training on upper extremity (UE) function of patients with chronic stroke.

DESIGN: A randomized controlled single-blinded trial.

SETTING: An outpatient rehabilitation clinic of a tertiary hospital.

POPULATION: Thirty-three patients with chronic hemiplegic stroke.

METHODS: We developed 8 Kinect2Scratch games. The participants were randomly assigned to either a Kinect2Scratch game group or a therapist-based training group. The training comprised 24 sessions of 30 minutes over 12 weeks. The primary outcome measure was the Fugl-Meyer UE scale and the secondary outcome measures were the Wolf Motor Function Test and Motor Activity Log. Patients were assessed at baseline, after intervention, and at the 3-month follow-up. We used the Pittsburgh participation scale (PPS) to assess the participation level of patients at each training session and an accelerometer to assess the activity counts of the affected UE of patients was used at the 12th and 24th training sessions.

RESULTS: Seventeen patients were assigned to the Kinect2Scratch group and 16 were assigned to the therapist-based training group. There were no differences between the two groups for any of the outcome measures postintervention and at the 3-month follow-up (all $P>0.05$). The level of participation was higher in the Kinect2Scratch group than in the therapist-based training group (PPS 5.25 *vs.* 5.00, $P=0.112$). The total activity counts of the affected UE was significantly higher in the Kinect2Scratch group than in the therapist-based training group ($P<0.001$).

CONCLUSIONS: Kinect2Scratch game training was feasible, with effects similar to those of therapist-based training on UE function of patients with chronic stroke.

CLINICAL REHABILITATION IMPACT: Kinect2Scratch games are low-cost and easily set-up games, which may serve as a complementary strategy to conventional therapy to decrease therapists' work load.

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KEY WORDS: Stroke; Upper extremity; Video games; Rehabilitation.

Functional deficits of the upper extremities (UE) are strongly associated with the quality of life of stroke survivors.[1, 2] Approximately 70% of the patients in the acute post-stroke phase experience some UE disability. This disability persists in about half of the patients in the chronic phase.[3, 4] A variety of interventions were suggested to improve UE function, of which high intensity repetitive task training has the greatest benefits.[5] Such therapy requires extensive guidance from the therapist to deliver treatment, which is both costly and time consuming for the therapists. Hence, a low-cost intervention administered without extra effort on the part of therapists is required. Virtual reality and interactive video games have recently emerged as alternative approaches for rehabilitation. These interventions could facilitate high volume practice and decrease the demands on the time of the therapists. However, the cost of a virtual reality system and the requirement for specialist technical support limits the availability of these systems. Commercial exergames, such as Xbox Kinect games (Microsoft Corp, Redmond, Washington, USA), are more affordable than virtual reality systems. Because the commercial games are not specifically designed for therapeutic use, most patients with hemiplegic stroke are either too weak to play the games or use undesirable compensatory movements to play the games.[6] There is a need to develop feasible, effective and low-cost exergames for use in post-stroke rehabilitation.

Choosing appropriate motion sensors is important when developing UE motion-controlled games for patients with hemiplegic stroke. The Microsoft Kinect ™, an infrared camera-based sensor, is preferable for hemiplegic patients, because a player can use it to play a game via body movement without the need for handheld controllers. The original Kinect sensor design identified player's joint displacement by measuring the physical distance between joints. It needs to be calibrated when changing players. Chang et al[7] modified the design to estimate the angle changes, thus, making it more convenient to use. MIT's Scratch[8] is a software that is widely used by learner game-developers to develop games. Typically, Scratch games are controlled by a computer mouse or keyboard. A Scratch extension is a separate program that extends the capabilities of the Scratch' program by connecting Scratch to external hardware devices. Howell developed Kinect2Scratch,[9] which allows body tracking data to be transferred from the Kinect sensor to Scratch. Using Kinect2Scratch allows players to play Scratch games by moving their extremities. We have previously shown that using Kinect2Scratch games for UE training is a feasible adjunctive program for children with cerebral palsy.[10] These Kinect2Scratch games could provide an alternative approach for UE motor training in order to decrease the time demands on therapists.

The aims of this study were: 1) to develop Kinect2Scratch games to train UE function for patients with chronic hemiplegic stroke; and 2) to compare the effects of Kinect2Scratch games training with equal length sessions of therapist-based training. We hypothesized that Kinect2Scratch games would be as effective as therapist-based training.

Materials and methods

Game development

In order to develop games, we used Scratch 2.0 as a source of games on console systems. Programming is done by inserting command blocks, which form scripts that control the interactive interface. Kinect2Scratch sends data from the Microsoft Kinect controller to Scratch. The Kinect v1, used in this study, can only detect the shoulder, elbow and wrist motion; therefore, we designed the games focusing on training the proximal part of the affected UE. We incorporated several feedback systems, including showing the number of correct movements or target objects on the screen, and adding cheering or clapping sounds to increase the enjoyment of patients. We also designed an alarm system to alert patients when compensatory movements were detected.

Participants

Screening and recruitment process

Patients with hemiplegic stroke who received outpatient rehabilitation training in a tertiary hospital were screened for eligibility. The inclusion criteria were as follows: 1) both a clinical and imaging-based diagnosis of a unilateral stroke, more than 6 months prior to the trial; 2) having active movement of the affected proximal UE; 3) Mini Mental State Exam score greater than 20;[11] and 4) age more than 18 years. Participants were excluded if they had bilateral hemispheric or cerebellar lesions, severe aphasia, significant visual field deficits or hemineglect and any conditions that would prevent adherence to the rehabilitation protocol.

Randomization

Participants were randomly allocated to either a Kinect2Scratch or therapist-based training group using a 1:1 randomization sequence prepared by an individual not involved in any other study procedure.

Allocation was stratified according to the baseline total score on the Fugl-Meyer Assessment UE (FMA-UE)[12]

>38 or ≤38 and duration of onset of <2 years or ≥2 years. The assignment of participants to specific groups was concealed using opaque envelopes, which were opened after the patient completed the baseline assessment.

Intervention

The Template for Intervention Description and Replication (TIDieR) checklist was used to describe the Kinect2Scratch games and therapist-based interventions. Both interventions were administered during outpatient occupational therapy sessions at the occupational training room. The participants were randomized to receive either Kinect2Scratch games or therapist-based training for 30 minutes, with 2 or 3 sessions per week, resulting in 24 sessions over 3 months. Both interventions were supervised by a licensed occupational therapist, who was trained in treatment protocols and study procedures to ensure the consistency of intervention delivery. All participants also received training for activity of daily living for 15 minutes and conventional hand function training for 30 minutes.

Kinect2Scratch games group

We designed 8 games (6 unimanual and 2 bimanual) for UE training (Figure 1). A detailed description of the 8 games is provided in Table I. The participants in the Kinect2Scratch group were presented with 3-4 games per training session. The supervised occupational therapist chose the games and adjusted the levels of difficulty according to the ability and needs of each participant. The gaming system allows certain parameters to be adjusted. These include the object speed, interval between successive objects, the probability distribution of the object start positions and adding obstacles on the pathway. Those who had difficulty moving the affected UE could use their unaffected UE to assist the movements. The therapist instructed the participants how to play the games at the first session and when a new game was delivered. The therapist also monitored the safety of patients during the intervention.

Table I.—*Description of the 8 games.*

Game	Description
Whack-a-mole	The patient performs shoulder elevation/depression and abduction/adduction, elbow flexion-extension to raise and position the hammer to target moles, and shoulder external/internal rotation to lower the hammer to hit moles in the game
Harvest carrots	The patient performs shoulder flexion with elbow extension to pull the carrots then shoulder adduction to cross the midline and put the carrots on the ground
Picking apples	The patient performs shoulder flexion-extension/adduction-abduction/external-internal rotation to pick apples from the tree and place them into the basket
Bowling	The patient performs shoulder extension/flexion and elbow extension/flexion to play the bowling games
Alien attack	The patient claps their hands (using bilateral shoulder abduction-adduction motion) to launch missiles at the aliens
Hungry shark	The patient needs to use the affected UE in an up-and-down motion to control the shark eating the incoming fishes
Hungry ant	The patient uses multi-directional reaching motion to control an ant searching for cookies
Boxing	The patient performs shoulder flexion/adduction with elbow flexion to hit against the opposing boxer

Therapist-based training group

Patients in the therapist-based training group practiced a variety of bilateral or unilateral UE movement training under one-on-one supervision of the therapists. Patients received specific training for the UE consisting of single joint (shoulder, elbow, forearm) or a combination of multi-joints (such as combining shoulder abduction/adduction

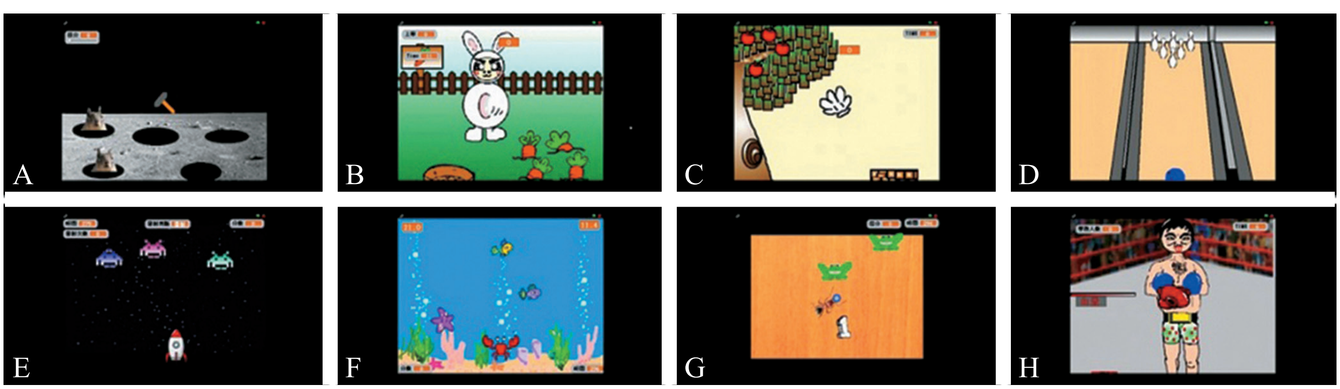

Figure 1.—Screen images of 8 Kinect2Scratch games. A) Whack-a-mole; B) Harvest carrots; C) Picking apples; D) Bowling; E) Alien attack; F) Hungry shark; G) Hungry ant; H) Boxing.

and elbow flexion/extension) movements. Each training program was personalized to suit the ability and needs of participants. The therapist gave verbal feedback about the performance of participants, and encouraged them in their activities. The therapist also corrected the participants' movements manually, if necessary. The therapists could provide physical assistance to the affected UE for those who had difficulty moving it. At each session, the patients received 3-4 UE movement patterns training.

Outcome measures

Primary outcome measure

We used FMA-UE as a primary outcome measure. The FMA-UE[12] assessed the movements of the proximal and distal parts of the UEs with the total score ranging from 0 to 66. We further divided the total FMA-UE score into proximal (shoulder, elbow, and forearm; FMA-PROX) and distal (wrist and hand; FMA-DIS) scores. The psychometric properties of the FMA-UE in people with stroke are satisfactory.[13, 14]

Secondary outcome measure

We used both the Wolf Motor Function Test (WMFT) and Motor Activity Log (MAL) as secondary outcome measures. The WMFT is a valid and reliable test used to assess arm motor performance.[15, 16] The performance time (WMFT-TIME) and functional ability scale (WMFT-FAS) of the tasks were evaluated. The maximum time allowed to complete a task is 120 s, and a six-point scale is used to score functional ability. The MAL is a self-rated assessment, measuring the amount of the affected hand usage (MAL-AOU) and the quality of movement (MAL-QOM) during 30 daily functional tasks.[17, 18] The score of each item ranges from 0 to 5, and higher scores indicate more frequent usage or a higher quality of the movements performed. The MAL is a good, valid, and responsive scale.[19, 20] An assessor blinded to the group allocation performed the assessments at baseline, post-treatment, and at the three-month follow-up.

The supervised therapist recorded the adherence of the participants and used the Pittsburgh Participation scale (PPS) to grade the degree of the participant's engagement in either Kinect2Scratch or therapist-based training. The PPS[21] is a six-point scale of observed engagement in treatment (effort and motivation). The PPS has high interrater reliability.[21]

Using a wrist-worn accelerometer to measure UE activity of stroke patients has been demonstrated to be a reliable and valid method.[22, 23] We used triaxial ActiGraphGT3X+ accelerometers[24] to assess the amount of the affected UE movement during Kinect2Scratch or therapist-based therapy sessions. The acceleration was recorded along 3 axes at a frequency of 30Hz. The ActiLife 6 software was used to download raw data and convert acceleration into activity counts. Total activity counts (TAC), which was a composite vector magnitude from 3 axes, was calculated. The average value of TAC of the affected UE at the 12th and 24th training session was used for the statistical analysis.

During the intervention period any adverse events were monitored and recorded. The study protocol was reviewed and approved by the relevant ethics committees and was registered in ClinicalTrials.gov. Each participant provided written consent before any study-related procedure was undertaken.

Sample size calculation

There was no study to compare the effects of Kinect2Scratch game-based training and therapist-based training before. A priori sample size calculation was based upon previously published data on the FMA outcome measures.[25, 26] The overall effect size $\bar{d}$ was calculated by transforming effect size d of each study. The calculated overall effect size $\bar{d}$ for the FMA is 1.04. We used G*Power software to estimate the number of participants needed for this project. With an overall effect size of 1.04, a statistical power of 0.80, and a two-sided type I error of 0.05, the sample size calculation resulted in 16 participants per group.

Statistical analysis

The Statistical Package for Social Science (SPSS 22.0 for Windows, SPSS, Chicago, IL, USA) was used for statistical analyses. Descriptive statistics were used to estimate the demographic and clinical characteristics of the participants. For the quantification of the intervention or maintenance effects of each intervention, we used the change score overtime for further analyses. The change score was determined by subtracting the pretraining score from the post-training score or the follow-up score. The analysis was conducted in accordance with the "intention-to-treat" principle. If data for certain outcomes were missing, the most recent observations were carried forward. In this study, nearly all continuous data were non-normally distributed (tested by Kolmogorov-Smirnov Test). Therefore, the between groups comparisons were analyzed by the Mann-Whitney U Test or χ^2 test, within-group comparisons were analyzed by the Wilcoxon signed rank-test. All significant tests were two-tailed, and differences were considered to be statistically significant at a P value <0.05.

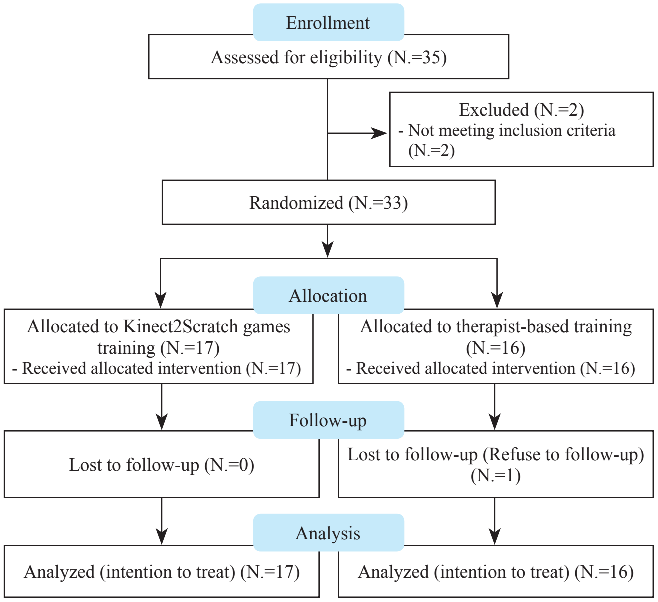

Figure 2.—Flowchart of the participants through the study.

Results

Baseline characteristics of the participants

We screened 35 subjects for eligibility; 33 met the inclusion criteria and underwent randomization with 17 being assigned to the Kinect2Scratch group and 16 to the therapist-based training group. One patient in the therapist-based training group refused to undertake the 3-month follow-up assessment. Figure 2 describes the flow of participants through each stage of the study period.

Both groups showed similar demographic and clinical characteristics (Table II).

Monitoring of adverse effects

There were no serious side effects during the intervention period. Most participants in the Kinect2scratch group complained of UE soreness after training, but the soreness subsided spontaneously.

None of the participants needed further treatment. There was no such complaint in the therapist-based group.

Treatment effects on the outcome measures

Within-group comparison

Table III, IV provide a summary results for each study group post intervention and at the 3-month follow-up point. After intervention, the Kinect2scratch group showed significant improvements in FMA-UE (P=0.001), FMA -PROX (P=0.001) and FMA-DIS (P=0.017). The Kinect2scratch group also had significant improvements in WMFT-TIME (P=0.004) and MAL (AOU and QOM, P=0.009, 0.003 respectively). The therapist-based group

TABLE II.—*Baseline characteristics of study participants.*

Characteristics	Kinect group (N.=17)	Control group (N.=16)	P
Age, years	56.58 (45.38-64.29)	61.38 (48.62-66.29)	0.488
Gender, man	12 (70.59%)	12 (75%)	0.619
Side of lesion (right hemisphere)	10 (58.82%)	10 (62.50%)	0.556
Type of stroke			0.543
Hemorrhage	7 (41.18%)	4 (25%)	
Infarction	10 (58.82%)	12 (75%)	
Poststroke duration (months)	29 (14.5-40)	37.5 (23-42.5)	0.26
First stroke	16 (94.11%)	15 (93.75%)	0.742
Functional status			
MMSE	27 (25-29)	28 (24.25-28)	0.444
FMA-UE			
PROX	30 (22-31.5)	26 (23.25-30.75)	0.631
DIS	7 (3-13)	6.5 (0.25-13.5)	0.683
Total	35 (28-44)	33.5 (23.75-43)	0.709
WMFT			
Time	10.23 (5.89-17.19)	7.85 (5.05-10.77)	0.326
FAS	2.67 (2.07-2.87)	2.5 (1.85-3.13)	0.736
MAL			
AOU	1.73 (0.88-2.36)	1.14 (0.83-1.47)	0.087
QOM	0.71 (0.43-1.69)	0.67 (0.31-1.17)	0.276

Values are expressed as median(IQR) or N(%).
MMSE: Minimental state examination; FMA-UE: Fugl-Meyer Assessment-upper extremity; PROX: Fugl-Meyer Assessment proximal upper extremity; DIS: Fugl-Meyer Assessment distal upper extremity; WMFT-time: performance time of the Wolf Motor Function Test; WMFT-FAS: functional ability scale of the Wolf Motor Function Test; MAL-AOU: motor activities log – amount of use; MAL-QOM: motor activities log – quality of movement.

TABLE III.—*Within group comparison pre, post intervention in the 2 groups.*

	Kinect (N.=17)	P	Control (N.=16)	P
FMA-UE				
PROX				
Pre	30.00 (22.00-31.50)	0.001*	26.00 (23.25-30.75)	0.005*
Post	32.00 (24.50-34.50)		27.5 (23.25-32.00)	
DIS				
Pre	7.00 (3.00-13.00)	0.017*	6.50 (0.25-13.50)	0.116
Post	7.00 (2.50-14.00)		7.00 (1.25-16.75)	
Total				
Pre	35.00 (28.00-44.00)	0.001*	33.50 (23.75-43.00)	0.014*
Post	36.00 (31.00-50.50)		36.00 (25.00-49.50)	
WMFT				
Time				
Pre	10.23 (5.89-17.19)	0.004*	7.85 (5.05-10.77)	0.006*
Post	8.24 (4.22-11.20)		5.85 (3.79-8.64)	
FAS				
Pre	2.67 (2.07-2.87)	0.799	2.50 (1.85-3.13)	0.338
Post	2.73 (2.10-3.04)		2.465 (1.868-3.35)	
MAL				
AOU				
Pre	1.73 (0.875-2.36)	0.009*	1.14 (0.83-1.47)	0.066
Post	2.30 (1.480-2.62)		1.29 (0.86-2.58)	
QOM				
Pre	0.71 (0.425-1.69)	0.003*	0.665 (0.31-1.17)	0.15
Post	1.39 (0.72-1.96)		0.745 (0.47-1.38)	

Values are expressed as median(IQR).
FMA-UE: Fugl-Meyer Assessment-Upper Extremity; PROX: Fugl-Meyer Assessment proximal upper extremity; DIS: Fugl-Meyer Assessment distal upper extremity; WMFT-Time: performance time of the Wolf Motor Function Test; WMFT-FAS: functional ability scale of the Wolf Motor Function Test; MAL-AOU: Motor Activities Log: amount of use; MAL-QOM: Motor Activities Log – quality of movement; Pre: preintervention; Post: postintervention.
*Statistically significant.

only showed significant improvements in FMA-UE and FMA-PROX (P=0.014, 0.005 respectively) and WMFT-TIME (P=0.006).

At follow-up, the Kinect2scratch group only showed significant improvements in FMA-UE (P=0.015), FMA-PROX (P=0.01) and WMFT-TIME (P=0.001). The therapist-based group showed significant improvements in FMA-UE and PROX (P=0.003, <0.001 respectively) and WMFT (TIME P=0.002, FAS P=0.037).

Between-group comparison

There were no between-group differences for any of the change scores, either postintervention or at the 3-month follow-up point (Table V, VI).

The level of participation was higher in the Kinect2Scratch group than in the therapist-based group (PPS 5.25 [5.00-5.50] *vs.* 5.00 [4.75-5.25], P=0.112). The Kinect2Scratch group showed significantly higher activity counts of the affected UE compared with the therapist-based group (TAC 5239.33 [4198.08-7149.98] *vs.* 2877.25 [2517.21-3702.76], P<0.001).

Discussion

Our study showed that 24-sessions Kinect2Scratch video game training to improve UE function in patients with chronic hemiplegic stroke is feasible. Training with Kinect2Scratch games was as effective as the therapist-based intervention.

In this study we used low-tech self-designed motion-controlled video games rather than the games developed by dedicated laboratory facilities or game-development studios. Our results are comparable to those of previous related studies. A review by Laver *et al.*[27] found that virtual reality and interactive video gaming showed similar benefits in improving UE function compared to conventional therapy approaches. Virtual reality may be more beneficial in improving UE function when used as an adjunct to the usual care to increase overall therapy time.[27]

In our study design, the contents of training in the two groups were similar, as both groups focused on the movements of the proximal UE, but the training delivery methods were different. In the games group, the therapist only had to configure the program settings and monitor the safety of

TABLE IV.—*Within group comparison between preintervention and 3 months follow-up in the 2 groups.*

	Kinect (N.=17)	P	Control (N.=16)	P
FMA-UE				
PROX				
Pre	30.00 (22.00-31.50)	0.01*	26.00 (23.25-30.75)	<0.001*
Follow-up	31.00 (23.00-35.00)		27.00 (25.00-33.75)	
DIS				
Pre	7.00 (3.00-13.00)	0.105	6.50 (0.25-13.50)	0.081
Follow-up	8.00 (2.00-15.50)		7.50 (1.25-17.00)	
Total				
Pre	35.00 (28.00-44.00)	0.015*	33.50 (23.75-43.00)	0.003*
Follow-up	37.00 (29.50-51.00)		36.00 (25.50-52.25)	
WMFT				
Time				
Pre	10.23 (5.89-17.185)	0.001*	7.845 (5.048-10.77)	0.002*
Follow-up	6.40 (4.135-8.595)		4.89 (2.975-5.455)	
FAS				
Pre	2.67 (2.065-2.87)	0.254	2.50 (1.85-3.133)	0.037*
Follow-up	2.67 (2.10-2.87)		2.53 (1.85-3.32)	
MAL				
AOU				
Pre	1.73 (0.875-2.355)	0.089	1.14 (0.83-1.465)	0.141
Follow-up	2.10 (1.11-2.565)		1.29 (0.713-2.08)	
QOM				
Pre	0.71 (0.425-1.685)	0.061	0.665 (0.305-1.17)	0.151
Follow-up	1.31 (0.575-2.02)		0.655 (0.323-1.295)	

Values are expressed as median(IQR).
FMA-UE: Fugl-Meyer Assessment-Upper Extremity; PROX: Fugl-Meyer Assessment proximal upper extremity; DIS: Fugl-Meyer Assessment distal upper extremity; WMFT-Time: performance time of the Wolf Motor Function Test; WMFT-FAS: functional ability scale of the Wolf Motor Function Test; MAL-AOU: Motor Activities Log – amount of use; MAL-QOM: Motor Activities Log – quality of movement; Pre: preintervention.
*Statistically significant

TABLE V.—*Comparing the change score postintervention between the 2 groups.*

	Kinect (N.=17)	Control (N.=16)	P
FMA UE			
PROX	2.00 (1.00-4.50)	2.00 (1.0-3.75)	0.382
DIS	1.00 (0.00-2.00)	0.50 (0.00-2.00)	0.817
Total	4.00 (2.00-5.00)	4.00 (1.00-5.75)	0.736
WMFT			
Time	-2.175 (-6.54--0.154)	-2.45 (-4.601--0.925)	0.986
FAS	0.667 (-0.133-0.20)	0.033 (-0.166-0.133)	0.606
MAL			
AOU	0.346 (-0.556-0.839)	0.107 (-0.078-0.482)	0.345
QOM	0.276 (0.03-0.623)	0.125 (-0.044-0.224)	0.276

Values are expressed as median (IQR)
FMA-UE: Fugl-Meyer Assessment-Upper Extremity; PROX: Fugl-Meyer Assessment proximal upper extremity; DIS: Fugl-Meyer Assessment distal upper extremity; WMFT-Time: performance time of the Wolf Motor Function Test; WMFT-FAS: functional ability scale of the Wolf Motor Function Test; MAL-AOU: Motor Activities Log – amount of use; MAL-QOM: Motor Activities Log – quality of movement.

TABLE VI.—*Comparing the change scores at 3 months follow-up between the 2 groups.*

	Kinect (N.=17)	Control (N.=16)	P
FMA UE			
PROX	2.00 (2.00-4.00)	2.00 (1.0-4.00)	0.736
DIS	1.00 (0.00-2.00)	1.00 (0.00-2.00)	0.958
Total	3.00 (2.00-5.50)	3.50 (1.00-6.00)	0.873
WMFT			
Time	-2.789 (-7.057 to -0.864)	-3.083 (-4.936 to -1.364)	0.709
FAS	0.00 (-0.133-0.267)	0.067 (0.00-0.267)	0.631
MAL			
AOU	0.38 (-0.16-0.69)	0.055 (0.00-0.233)	0.326
QOM	0.207 (-0.12-0.417)	0.068 (0.00-0.198)	0.51

Values are expressed as median (IQR)
FMA-UE: Fugl-Meyer Assessment-Upper Extremity; PROX: Fugl-Meyer Assessment proximal upper extremity; DIS: Fugl-Meyer Assessment distal upper extremity; WMFT-Time: performance time of the Wolf Motor Function Test; WMFT-FAS: functional ability scale of the Wolf Motor Function Test; MAL-AOU: Motor Activities Log – amount of use; MAL-QOM: Motor Activities Log – quality of movement.

the intervention. As there were no serious adverse events, we suggest the safety monitoring could be done by patients' family or rehabilitation assistants. The program settings and progressive modifications can be done quickly and even can be done remotely. Therefore, the Kinect2Scratch games could be used as an alternative therapy for stroke rehabilitation to decrease the time-demand for therapists. The cost-effectiveness of the Kinect2Scratch games either as a part of clinical UE training program or as a home-based training program deserves further examination.

Intensive and repetitive use of the affected limb may induce positive effects on neuroplasticity, leading to improvement of motor function.[28, 29] The limb movements performed during video-game based therapy were about three times greater than those performed during conventional therapy.[30] The motion-controlled video games training system, therefore, is an important step towards achieving the required number of repetitions of exercises.[31] Our study found that the amount of movement of the affected UE in the Kinect2Scratch group was nearly twice the amount in the therapist-based therapy. However, this did not translate into significantly greater improvement of UE function compared to that in the therapist-based group. Laver *et al.*[27] noted that a higher dose (more than 15 hours of the total intervention) was preferable as were customized virtual reality programs. Results from animal studies suggested that high doses and multiple repetitions are required to induce behavioral changes following brain injury.[32] In our study, high intensity training in terms of many repetitions was provided; however, the total dose (12 hours of training) may not be adequate. A longer intervention period may potentially provide a different result. Additionally, the two groups underwent only 30 minutes of different trainings during each 75-minute session. The relatively short duration of training may be another reason why between-group differences were not seen.

With respect to the benefit of task repetitions, we were aware of the risk of repetitive injury. There was no consensus on the optimal duration for each video game intervention. We found the Kinect2Scratch participants usually complained of UE soreness after a 30-minute Kinect2Scratch games intervention. We think that 30 minutes may be the upper limit for such highly repetitive movements in game training. Providing adequate rest during the training sessions and using variable movement patterns to play games could prevent repetitive injuries. Under such training principles, we did not find any persistent or severe soft tissue injury problems during our study period.

It was reported that the level of patients' engagement is related to impairment reduction during digital game-based therapy in stroke.[33] The ludic aspects of games may help patients to be more motivated during the videogames exercise compared to conventional rehabilitation.[34] Moreover the visual biofeedback is identified as helping to induce neuroplasticity,[35] promoting higher levels of active participation.[36] The Kinect2scratch group showed a higher level of participation compared with the therapist-based group, as shown by PPS; however, the difference was not significant. Our Kinect2Scratch games were not created by professional game-developers; therefore, the games may not contain as many ludic elements or high-quality graphics and sounds as commercial games. This is most likely the reason why we did not observe a significantly higher level of engagement in the game group compared to the therapist-based group.

When considering the retention effects of virtual rehabilitation in stroke, a review by Aminov *et al.*[37] reported small to medium effects of virtual rehabilitation for both body structure/function and activity level outcomes at the follow-up stage, but not for participation domains (assessed by MAL). We had similar results. In our study the functional gain in MAL was not maintained at the 3-month follow-up, as observed in the within-group comparison. Further studies are required to analyze the poor retention effect in the participation domain for Kinect2Scratch game therapy.

Limitations of the study

There are some limitations to consider for this study. First, we only recruited subjects with active movement of the affected proximal UE; therefore, our findings cannot be extrapolated for subjects with no active movement of the affected proximal UE.

Second, we used the first generation of Kinect sensor; therefore, we could only design games that involve the shoulder and elbow to play the games. In the future, the new generation of Kinect should be used to design the games incorporating both fine motor and virtual ADL training to increase the clinical application value of the Kinect2Scratch games. Additionally, the Scratch programming environment can only be created and displayed using two-dimensional platforms. Two-dimensional displays are not immersive and limit the design of UE motion training. We can only speculate whether a more immersive three-dimensional experience (for example using the Unity programming language) may increase the effect of motor training.

Conclusions

Kinect2Scratch game therapy is a feasible intervention, well-accepted by patients with chronic hemiplegic stroke. It is as efficacious as the therapist-based UE training in our study. The use of Kinect2Scratch games may serve as a complementary strategy to conventional therapy to decrease the therapists' workload.

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