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Original Articles
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Improving Walking, Muscle Strength, and Balance in the Elderly with an Exergame Using Kinect: A Randomized Controlled Trial

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Abstract

Background: Many issues prevent elderly individuals from exercising in daily life. There is a need for a system that allows elderly individuals to engage in exercise regularly at a low cost. We developed an exergame that uses a Kinect® sensor (Microsoft Corp., Redmond, WA) and conducted a randomized controlled trial of the effects of using this exergame on muscle strength and balance in healthy elderly individuals.
Subjects and Methods: We enrolled 57 healthy elderly individuals and randomly divided them into an intervention group ($n=29$) and a control group ($n=28$) using a table of random numbers. All participants underwent gait analyses and were examined using the Berg Balance Scale (BBS), Functional Reach Test (FRT), and the 30-second chair-stand (CS-30) test before the intervention. Participants in the intervention group played the exergame once or twice a week, up to a total of 24 times. The tests were repeated after intervention, and the scores were compared with those obtained before intervention.
Results: Our results indicated that walking, muscle strength, and motor function improved in participants in the intervention group. Decreased double standing time ($P=0.03$), minimum foot clearance ($P=0.04$), BBS scores ($P<0.01$), CS-30 scores ($P<0.01$), and FRT scores ($P<0.01$) significantly improved in the intervention group compared with values in the control group.
Conclusions: The Kinect-based exergame developed in this study was found to be effective in improving walking, muscular strength, and balance in elderly people.

Introduction

As Japan develops into a super-aged society, innovative methods are required to encourage elderly individuals to maintain their functional level in terms of motor function and activity level and, from a socioeconomic viewpoint, to prevent falls and accidents. Many exercise[1–4] regimens have been implemented to encourage elderly individuals to engage in exercise. An exercise support system is needed that offers effective exercise, allowing elderly individuals to exercise regularly and reducing the burden on exercise instructors and exercise event organizers.

Exergames—videogames that involve exercise—are currently under consideration as a method of promoting exercise among elderly individuals. Intervention with exergames has been demonstrated to improve balance and performance.[5–8] Exergames have recently been developed with different types of sensing functions, such as acceleration and load measurement. In recent years, a new, simple motion sensor called Kinect® (Microsoft Corp., Redmond, WA) was released in the market. Systems using Kinect can instantaneously acquire data on, for instance, joint angles, facilitating the development of games involving moving on-screen avatars. As a result, these exergames are easily comprehended by elderly individuals, who may have little experience playing videogames.

We used the features of Kinect to create an exergame for elderly individuals. We hypothesized that elderly individuals could improve their motor function by using the exergame. To verify this hypothesis, we conducted a randomized controlled trial of the effects of playing the exergame on exercise function in elderly individuals.

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Subjects and Methods

Participant data

Fifty-nine locally residing, healthy elderly individuals were considered as study participants. Finally, 57 participants were enrolled in the study. Their mean age was 69.25 (standard deviation [SD] = 5.41) years. All participants had normal scores for the Mini-Mental State Examination.[9] Their mean score for an index of exercise function, the Motor Fitness Scale,[10] was 11.98 (SD = 2.18) points, indicating that no participants had any significant motor functional impairment.

All of the participants were randomly allocated to an intervention group or a control group using a table of random numbers by an expert biostatistician with no relationship with the study. The intervention group played the exergame. After randomization, the intervention and control groups included 29 and 28 participants, respectively. However, one woman in the intervention group and one man in the control group withdrew halfway through the study, and the final analyses were performed on a total of 54 participants.

Based on the result of our pilot study,[11] the effect size was calculated as 0.8. When the sample power was set at 80 percent, the level of significance was set at 0.05, and the assumed attrition rate was set at 10 percent, at least 26 participants each were necessary for the intervention and control groups. At recruitment, 57 participants agreed to participate in this study, but one from the intervention group and two from the control group withdrew from the study soon after the baseline measurement. However, the number of participants was still assumed to be enough to detect statistically significant differences (Table 1).

This study was conducted after receiving approval from the ethical committee of Tohoku Fukushi University (approval number RS1203062).

Intervention frequency

The intervention period was September 15, 2013 through December 3, 2013. The mean duration of intervention was 65.34 (SD = 9.63) days. A physical therapist, a student, and game development staff operated the personal computer (PC) for the exergame.

Elderly individuals in the intervention group played the exergame, with intervals, for 40 minutes to 1 hour. This protocol was repeated two to three times per week, up to a total of 24 times. Individuals in the control group were instructed to go about their daily lives as usual (Fig. 1).

Before engaging in the exergame, both the intervention and control groups underwent pre-intervention tests. After participants in the intervention group had played the exergame 24 times, the intervention and control groups underwent the same tests. Comparisons were made between the intervention and control groups and between scores obtained before and after the intervention.

Table 1. Baseline Characteristics of Trial Participants

Variable	*INT* (n = 28)	*CNT* (n = 26)	P *value*[a]
Female (number)	22	21	1.00[b]
Age (years)	70.07 (5.35)	68.50 (5.47)	0.26
Height (cm)	155.92 (8.76)	157.00 (6.79)	0.61
Weight (kg)	63.35 (12.88)	63.50 (9.10)	0.96
Body mass index (kg/m^2)	25.88 (3.60)	25.72 (2.99)	0.85
Mini-Mental State Examination	28.71 (1.65)	29.00 (1.74)	0.54
Motor Fitness Scale	12.10 (2.41)	11.85 (1.93)	0.66

Data are mean (standard deviation) values.
[a]By Student's *t* test.
[b]By chi-squared test.
CNT, control group; INT, intervention group.

Intervention game content (exercise program)

The intervention game content used Kinect and Kinect SDK version 1.5 (Microsoft) and Unity version 3.4.2 (Unity Technologies SF Inc., San Francisco, CA), a three-dimensional (3D) support tool/engine used with Kinect.

Apple game. In the apple game, targets resembling apples were distributed on a 3D coordinate system around the participants, who were instructed to use both arms to grab them. The game lasted for 90 seconds and included three levels of difficulty. At the easy level, participants were able to grab apples without much movement. However, as the level of difficulty increased, the targets were more widely distributed (Fig. 2a).

Tightrope standing game. In the tightrope standing game, participants had to place their feet along a straight line and stand as if they were standing on a tightrope (tandem standing). Similarly to the apple game, targets were distributed laterally and in front of the participants, who were instructed to grab them at specified times. The game lasted for 90 seconds and included three levels of difficulty (Fig. 2b).

Balloon popping game. In the balloon popping game, targets resembling balloons moved in an arc over the game screen in front of participants, who were instructed to pop them when they passed through the area where their buttocks were by bending their hips and knees and squatting down. The game lasted for 40–90 seconds and included four levels of difficulty. At the level of difficulty increased, the angle of knee bending required to pop the balloons increased, as did the number of balloons. Furthermore, the sensor acquired hip bending angle data during squatting, and an alert message, reading ''bend more,'' was displayed when the angle was insufficient (Fig. 2c).

One-leg standing game. In the one-leg standing game, participants were instructed to stand on one leg and use their knee to touch a ball that appeared in front it. Targets popped when participants touched them with the specified knee at the specified time. At the level of difficulty increased, the knee position became higher, and time that participants were required to hold the position increased. Furthermore, the sensor acquired hip bending angle data, and an alert message, reading ''lift higher,'' was displayed when the angle was insufficient (Fig. 2d).

Gait analysis

Gait analysis was performed in a motion analysis room using the 3D motion analysis system Cortex 2 (Motion

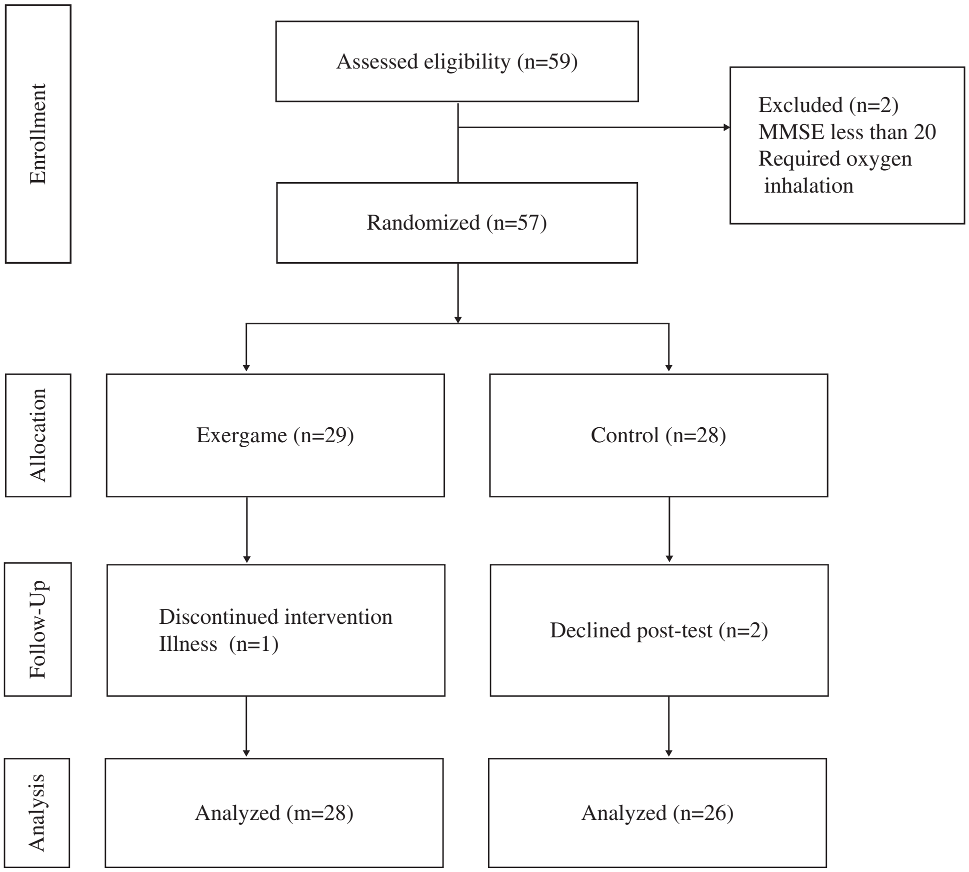

FIG. 1. Flow of participants through the study. MMSE, Mini-Mental State Examination.

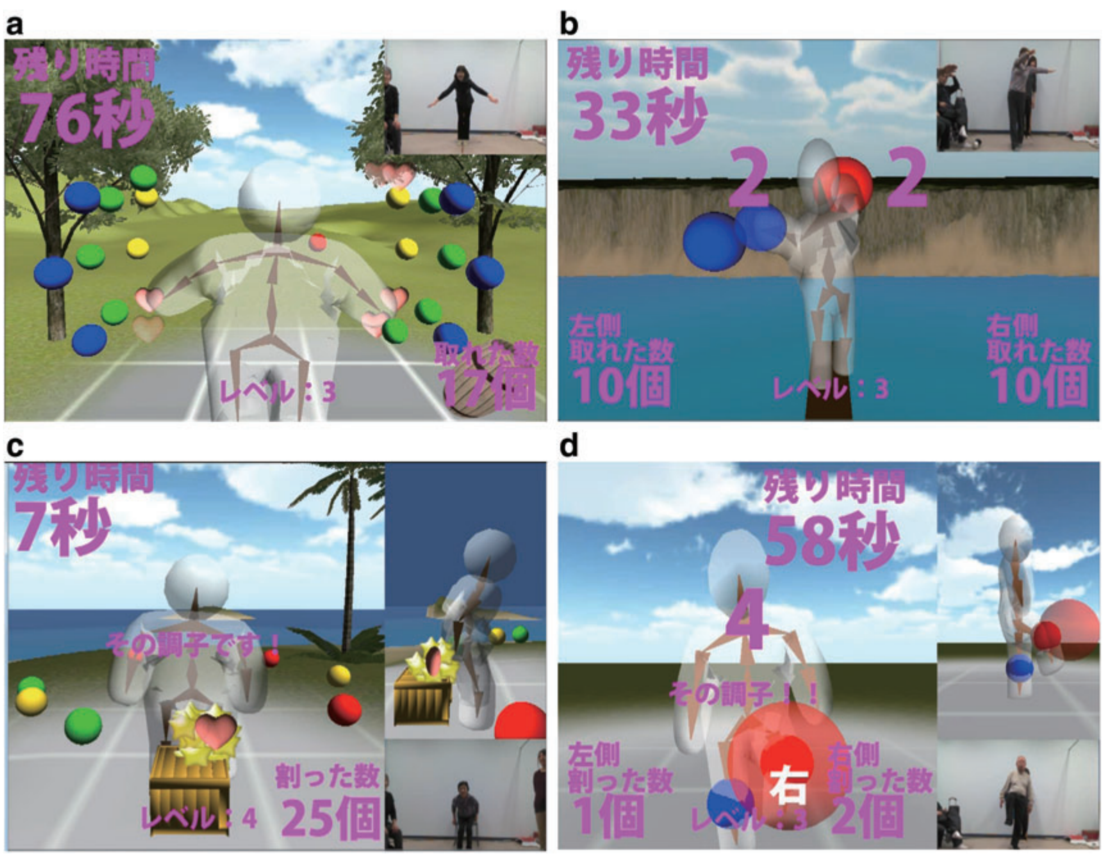

FIG. 2. Screen shots of the exergame: **(a)** apple game, **(b)** tightrope standing game, **(c)** ballon popping game, and **(d)** one-leg standing game. Color images available online at www.liebertonline.com/g4h

Analysis Corp., Santa Rosa, CA). Measurement markers were placed on the anterior superior iliac spines, greater trochanters of the femur, knees, lateral malleoli of the ankle, calcaneal regions, and dorsally on the second metatarsals, proximal to the metatarsophalangeal joints. Participants were instructed to walk the plane of the analysis path three times at their normal speed, and this was recorded. The recorded marker data were smoothed at 6 Hz and imported into Kine Analyzer (Kissei Comtec Corp., Nagano, Japan) software. The right leg was designated as the measurement leg, the heel strike and toe–ground detachment data were extracted, and gait cycle and walking variables were determined.

Minimum foot clearance

The height of the marker from the ground was calculated for participants in a resting standing position before gait cycle was measured. Right leg swing-phase sagittal plane data normalized to 200 points were obtained. Then, the height of the marker during resting was subtracted from the height of the marker from the ground (calculated above) to yield the minimum foot clearance (MFC) during the swing phase.

Performance tests

Berg Balance Scale. The Berg Balance Scale (BBS) was implemented according to the method of Berg et al.[12]

Functional Reach Test. To perform the Functional Reach Test (FRT), reflective markers were affixed to participants' right wrists, and the baseline was defined as a 90° anterior elevation of both arms from the standing position. From this position, participants were asked to reach forward as far as possible, which was defined as the maximum reach for the purposes of this study. Participants maintained each prescribed position for 3 seconds, and the difference from baseline was measured. This test was conducted three times to yield the maximum reach length.

30-second chair-stand test. For the 30-second chair-stand (CS-30 test) test,[13] the starting position involved participants sitting on a 40-cm-high stand, with both hands crossed against their chest. After the ''start'' signal, participants repeatedly stood up and sat down as quickly as possible. The number of repetitions participants were able to perform during 30 seconds was recorded.

Table 2. Walking Parameters

Variable, group	*Pre*	*Post*	*Difference (Post – Pre)*	*95% CI*	P *value*[a]
Velocity (m/minute)					0.30
INT	132.56 (17.41)	143.88 (16.35)	11.32	4.80–19.02	
CNT	137.21 (17.05)	144.21 (15.78)	7.00	−0.33 to 13.91	
Frequency (Hz)					0.14
INT	0.97 (0.09)	0.96 (0.08)	−0.01	−0.05 to 0.04	
CNT	0.97 (0.07)	0.92 (0.07)	−0.05	−0.10 to −0.01	
Cadence (steps/minute)					0.42
INT	124.68 (11.75)	129.74 (12.30)	5.06	1.15 to 8.95	
CNT	124.62 (9.60)	127.40 (8.96)	2.78	−1.27 to 6.83	
Stance phase time (seconds)					0.26
INT	0.60 (0.06)	0.57 (0.06)	−0.03	−0.05 to −0.01	
CNT	0.59 (0.05)	0.58 (0.04)	−0.01	−0.03 to 0.01	
Swing phase time (seconds)					0.97
INT	0.37 (0.03)	0.36 (0.03)	−0.01	−0.02 to 0.01	
CNT	0.37 (0.03)	0.37 (0.03)	0.00	−0.02 to 0.01	
Double standing time (seconds)					0.03
INT	0.12 (0.02)	0.11 (0.02)	−0.01	−0.02 to −0.01	
CNT	0.11 (0.02)	0.11 (0.02)	0.00	−0.01 to 0.01	
Stride (cm)					0.22
INT	128.80 (12.60)	135.26 (13.93)	6.46	2.22 to 10.69	
CNT	132.22 (12.51)	134.93 (14.43)	2.71	−1.68 to 7.11	
Minimum foot clearance (cm)[b]					0.11
INT	2.29 (0.67)	2.44 (0.59)	0.15	−0.05 to 0.34	
CNT	2.30 (0.71)	2.17 (0.60)	−0.13	−0.29 to 0.12	
Minimum foot clearance (cm)[c]					0.04
INT	1.78 (0.36)	2.16 (0.53)	0.38	0.14–0.61	
CNT	1.79 (0.37)	1.89 (0.46)	0.10	−0.18 to 0.31	

Data are mean (standard deviation) values.
[a]By Student's *t* test.
[b]All participants.
[c]This comparison was made only with participants who scored less than the median value in the pre-intervention tests (intervention group [INT], *n* = 14; control group [CNT], *n* = 13).
CI, confidence interval.

Table 3. Performance Test Results

Variable, group	*Pre*	*Post*	*Difference (Post – Pre)*	*95% CI*	P *value*[a]
Berg Balance Scale (score)					<0.01
INT	55.31 (56.00)	55.97 (56.00)	0.66	0.22–1.09	
CNT	55.68 (56.00)	55.64 (56.00)	−0.04	−0.44 to 0.36	
FRT (cm)					<0.01[b]
INT	29.36 (4.40)	33.88 (3.94)	4.52	30.46–59.90	
CNT	30.38 (3.85)	30.82 (4.08)	0.44	−10.85 to 19.70	
CS-30 test (repetitions)					<0.01
INT	17.54 (17.50)	24.04 (23.50)	6.50	4.46 to 8.54	
CNT	19.00 (18.00)	19.73 (19.00)	0.73	−0.72 to 2.18	

Data are mean (median) or mean (standard deviation) values.
[a]By Mann–Whitney U test.
[b]By Student's *t* test.
CI, confidence interval; CNT, control group; CS-30, 30-second chair stand; FRT, Functional Reach Test; INT, intervention group.

Statistical analysis

As non-normality was confirmed in the CS-30 test and the BBS, the Mann–Whitney U test was used. The chi-squared test was used to compare nominal scales, such as the sex of the participants. For other variables, comparisons were made between values obtained before and after intervention using Student's *t* test. Statistical analysis was performed using JMP Pro version 9.0.3 software (SAS Institute Inc., Cary, NC), and the significance level was set at 5 percent.

Results

No differences were evident between the intervention and control groups in variables such as age, sex, height, or weight. Over the 24-game sessions, one female participant withdrew because of illness, but the remaining 28 participants completed all game sessions. Two participants in the control group did not participate in postintervention tests.

Gait analysis

A comparison of pre- and postintervention gait analyses indicated that double standing time ($P = 0.03$) decreased after the intervention.

MFC

No significant difference in MFC was evident before and after intervention in the intervention or control groups (Table 2).

However, a comparison of participants who scored median values or lower in pre-intervention tests showed that MFC increased after intervention in the intervention group, whereas no difference was evident in the control group ($P = 0.04$) (Table 2).

BBS

A comparison of pre- and post-intervention BBS scores showed that these scores improved significantly in the intervention group ($P < 0.01$). No difference was evident in the control group (Table 3).

FRT

A comparison of pre- and post-intervention FRT showed a significant increase in the intervention group ($P < 0.01$). No difference was evident in the control group (Table 3).

CS-30 test

A comparison of pre- and post-intervention CS-30 test scores showed that these scores improved from 17.54 to 24.04 repetitions (approximately 27 percent) in the intervention group ($P < 0.01$). However, no difference was observed in the control group (Table 3).

Discussion

High-quality exercise instruction the elderly requires that individuals understand the movement of their own body. Because the exergame developed for this study uses Kinect, which senses the movement of individuals' joints and provides on-screen feedback based on these data, it was easy for users to confirm their body movements. Because the cost of the Kinect sensor is low and it does not require any prior preparation, we anticipate the use of this sensor in various exergames and exercise programs in the future.

Although no walking motions were included in the exergame developed for this study, our intervention improved reduced double standing time. Age-related changes in walking include increased double standing time.[14,15] That no change was evident in the control group suggests that, even without a specific walking element, the exergame caused an improvement in everyday walking movements. We believe that these effects were achieved by the squat movements of the balloon popping game and the one-leg standing game. The balloons would not pop, and an alert message appeared if participants' knees were insufficiently bent, ensuring the appropriate load was placed on the knee extensor muscle group. A squatting motion is said to require a knee bending angle of 60°–90°.[16] Playing the exergame appears to facilitate effective exercise in the absence of an instructor, and this may have caused the improvement in walking motion.

Increased double standing time in elderly individuals is used as an index for fall risk.[15,17,18] Reports have also implied that MFC is lower in elderly individuals with a history of falls,[19–22] suggesting that the intervention used in this study is highly effective in maintaining and improving motor function.

BBS and FRT scores improved significantly in the intervention group. This improvement must have been caused by the intervention because no changes in BBS scores occurred in the control group. Similarly, for the measurement of FRT, reach length improved significantly in the intervention group but not in the control group. This may be because these tests involved movements in which participants did not normally engage; however, when playing the apple game, participants had to use these positions, which led to improvements in time and reach. It is also possible that information, such as the number of seconds, displayed on the game screen during tasks and alert messages made it easier for participants to understand their own movements, making it easier to succeed.

This study has some limitations. First, we did not compare the game program in this study, which is characterized by feedback instruction to improve exercise performance, with that without the feedback. Therefore, although the overall program turned out to be effective in increasing the knee flexion angle, we could not conclude if the effect was based on the feedback information for the elderly to improve their movement.

This study demonstrated that exergames using Kinect, if appropriately designed, can help individuals to improve their motor and balance functions enjoyably.[11,23–25]

Conclusions

The exergame developed using a Kinect sensor in this study made it possible to acquire data such as knee and hip bending angles, height, and duration, which were then carefully reflected in the game content. As a result, improvement was observed in participants' motor functions, including lower limb muscle strength, walking, and balance. Our results suggest that it is possible to create an exergame that provides exercise instructions by designing game content that utilizes the characteristics of its sensor. If elderly individuals can operate the exergame independently, then high-quality exercise can be implemented regularly in a simple way, thereby helping to maintain and improve their motor function and activity.

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Author Disclosure Statement

No competing financial interests exist.

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