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The effects of exercise intervention using Kinect™ on healthy elderly individuals: A quasi-experimental study

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ABSTRACT

Purpose: Elderly persons may benefit from regular physical exercise to maintain or improve their quality of life and health status. Low adherence to physical exercise, however, is often a problem. A new type of videogames, "exergames", involving physical motion of the players has recently been developed and is expected to keep elderly people active. The purpose of this study is to examine the effect of a newly developed exergame on health benefits such as muscle strength and body balance of elderly people. Methods: We invited 24 healthy community-dwelling elderly persons aged 71.46 ± 4.8 years old (8 men and 16 women) volunteered for this study. We developed a new exergame program for using Kinect™ (Microsoft Co., Ltd. Redmond, WA) motion sensor. A single exergame session lasted approximately 30 minutes including warm-up and cool-down sessions. The participants are asked to play the exergame 2 - 3 times per week for 2.5 months at our institute. Maximal isometric muscular strength of major muscles of lower extremities and functional balance were examined before and after the exergame intervention. Result: All participants completed 24 sessions of the exergame program. There were significant improvements in maximal isometric muscular strength of hip joint flexion, and knee joint extension and flexion, of ankle joint dorsiflexion. Also MFC, a significant difference was noted between Pre and Post values. However, there was no statistically significant improvement in the functional balance test. Conclusion: Exergame developed in this study was found to be effective in improving muscular strength of lower extremities.

KEYWORDS

Exergame; Kinect; Elderly; Muscle Strength; Minimum Foot Clearance

1. INTRODUCTION

Japan's society is aging rapidly at a rate unseen anywhere else in the world [1].

For the elderly, maintaining motor function through exercise is becoming an urgent issue because it is an important element in ensuring physical health and preventing illnesses [2]. In recent years, "exergames" that incorporate exercise activities have been developed as video games marketed toward various age ranges and with multiple purposes of use. Video games reportedly improve motivation for training in patients [3,4], and it has also been reported that games using virtual reality content improved post-stroke upper limb motor function in individuals with cerebrovascular disease, while also maintaining motivation [5-7]. In addition to physical function, another report indicated that video games improved psychological scores in elderly individuals [8,9]. However, the application of game contents meant for general consumers to elderly individuals could cause various problems related to risk management or differences in motor function. Therefore, developing games for elderly individuals and presenting them as a system for improving various physical functions could mean that training elements could be increased so that games not only are fun but also offer considerable benefits to the elderly. If elderly individuals could improve their muscle strength by engaging in video games, this could be utilized as a new method in exercise instruction for the elderly. Here we developed an exergame for elderly individuals using Kinect™ and compared the Functional reach test (FRT) [10] and One-leg standing time [11] scores of regionally residing elderly subjects before and after using the game. The FRT is an index for lower limb muscle strength and balance function. We also compared Minimum foot clearance (MFC), which reportedly decreases with age and is a risk factor for trip-related falls [12-16], and investigated the possibilities of this exergame for the elderly.

2. METHODS

2.1. Subject Data

Subjects were regionally residing elderly individuals. Criteria for exclusion were individuals who had been forbidden to exercise by a doctor, those who had special daily lifestyle needs, and those who had any color vision or auditory abnormalities.

Subjects comprised 24 individuals (males: 8, females: 16) with a mean age of 71.46 ± 4.84 (mean ± standard deviation) years, mean height of 157.05 ± 6.11 cm, mean body weight of 64.60 ± 9.44 kg, and mean body mass index (BMI) of 26.1 ± 3.07. All subjects also had normal cognitive function. Mean Motor Fitness Scale (MFS) score [17] was 11.30 ± 2.26 and no subjects had significant motor function problems (**Table 1**).

No subjects had used a video game before participating in the present study. The purpose and content of this research were explained to each subject and their consent to participate was obtained. Before subjects used the exergame, lower limb muscle strength was measured and each subject underwent the FRT (Pre). Subjects played the exergame 2 - 3 times per week, for a total average of 25.83 ± 1.81 times, over an average period of 69.13 ± 6.96 days. After this, the same measurements taken before playing the game were taken again (Post). Subjects then returned to their usual daily lifestyles. To eliminate any carry-on effects, a mean period of 78.48 ± 8.81 days was left to pass before muscle strength and the FRT were measured again (Post2.5MO) (**Table 2**).

The present study was conducted after receiving the approval of the Tohoku Fukushi University research ethics committee (approval no: RS1203062).

2.2. Game Development Environment

Kinect™ SDK 1.5 (Microsoft Co., Ltd. Redmond) was used to develop the game content. Microsoft C# programming language was used to develop the software. The game content was developed using the free version of Unity Ver. 3.4.2 (Unity Technology Co., Ltd. San Francisco, CA) content development software.

Overall, the software was structured to comprise 10 min of automatic movement of the arms and legs as warming up before dividing into separate upper limb and lower limb games. The arm game involved 2 × 2 min sets and the leg game involved 1 - 5 min (depending on level) exercises for both left and right legs. Rest times were also incorporated so that the entire game could be completed in approximately 30 min.

Table 1. Baseline characteristics of trial participants.

Variable	Participants (n = 24)
Female (%)	67
Age (years)	71.46 (4.84)
Height (cm)	157.05 (6.11)
Weight (kg)	64.60 (9.44)
Body-mass index (BMI)	26.12 (3.07)
Motor fitness scale (MFS)	11.33 (2.26)

Values are mean (standard deviation) or %

Table 2. Exergame participation and post intervention interval.

Variable	Intervention	Post intervention interval
Participation (times)	25.83 (1.18)	-
Time (days)	69.13 (6.93)	78.48 (8.81)

Values are mean (standard deviation)

2.2.1. Arm Game

For the arm game, subjects stood in front of the Kinect™ device and skeletal data of subjects acquired with the Kinect™ was projected onto the screen. A total of 36 targets that appeared as 20 red, 10 green, and 6 blue apples arranged on a three-dimensional coordinate system were created, and the aim was for the subjects to grab these targets. This game aimed to make subjects stretch their arms forward to grab the targets with their hands, thereby improving FRT scores by making subjects perform the FRT action. Subjects played the game for 2 sets of 2 min (**Figure 1**) (Above).

2.2.2. Leg Game

The subjects stood in front of the Kinect™ device and had to lift one leg at a time to avoid the red planks (targets) that came down toward them from the screen. This game aimed to improve subjects' leg muscle strength and extend how long they could stand on one leg. The speed and height from which the targets came toward the subjects were fixed and One-leg standing time was changed by altering the depth of the targets. The subjects played

Figure 1. An actual game screen. Arm game (Above) and Leg Game (Below).

the game on both the left and right sides. One-leg standing time was set at 1 sec × 2 sets, 2 sec × 2 sets, 3 sec × 2 sets, 5 sec × 2 sets, 7 sec × 2 sets, 10 sec × 2 sets, 20 sec × 1 set, and 40 sec × 1 set. For each stage, the game ended if the subject failed twice. Subjects with unstable balance during the game were allowed to use a T-cane if they wished to (**Figure 1**) (Below).

2.3. Measurement Items

2.3.1. Muscle Strength Measurement Methods

Muscle strength was investigated by measuring maximum isometric muscle strength of the legs. A force sensor was used to take measurements. Pipe chairs were altered so that hip joint flexion, knee flexion/extension, and ankle dorsiflexion could be measured and each type of muscle strength could be measured. The force sensor underwent A/D conversion, was connected to a personal computer, recorded at 1 KHz sampling rate, and converted to Kgf. Then, to calculate the weight ratio by dividing body weight (%kgBW)

To measure leg muscle strength, we measured isometric contraction strength in subjects' right legs. While taking measurements, elements such as belt and wire length were adjusted so that the target joint was close to the center of the full range of motion. Subjects practiced numerous times before each measurement. Measurements involved subjects exhibiting maximum muscle strength for approximately 5 sec × 3 sets. Recorded values were normalized by dividing them by the body weight of each subject, after which Pre, Post, and Post2.5MO values were compared.

2.3.2. Hip Joint Flexion

Each subject sat on the edge of the pipe chair, whereupon a belt was wrapped around the center of their right thigh and a wire connected to the belt was dropped downward. A pulley attached to the bottom of the pipe chair was used to change directions and was connected to the force sensor. Subjects rested their left leg on the floor and flexed their right hip joint while supporting themselves with the chair and their left leg.

2.3.3. Knee Extension

Each subject sat in a pipe chair with force sensor attached to it. With their knees bent 90˚, a loop belt was affixed to the distal portion of the right lower leg. A wire with the length adjusted to fit the loop belt was then attached to the force sensor. Subjects placed their left leg on the floor to firmly support their body, held their right leg slightly above the floor, and then extended their right knee. When doing this, they were asked to be careful to avoid compensatory movements such as trunk lateroflexion.

2.3.4. Knee Flexion

Another pipe chair was placed facing the pipe chair to which the force sensor had been affixed. Subjects sat in the facing pipe chair and supported themselves firmly by placing their left leg on the ground. A loop belt was fixed to the distal portion of the right lower leg and a wire was fixed to the belt. This wire was connected to the force sensor affixed to the front pipe chair. Subjects were asked to lift their right leg slightly off the floor and bend their knee. When doing this, subjects were asked to be careful to avoid compensatory movements such as trunk lateroflexion and the pipe chair with the force sensor attached to it was firmly fixated.

2.3.5. Ankle Dorsiflexion

Each subject sat on the floor with their legs stretched forward. A pipe chair with a force sensor attached was fixated at a point that was an extension of a straight line from the subject's right leg. A loop belt attached to the force sensor was affixed to subjects' right fingernails and tibialis anterior muscle contraction was confirmed before subjects conducted ankle dorsiflexion. Subjects were asked to be careful to avoid compensatory movements such as trunk extension during measurements.

2.3.6. One-Leg Standing Time

Measurement of One-leg standing involved subjects gently lowering both hands while standing and slowly raising the left leg so that they were standing on the right leg only. Subjects were not allowed to balance with their hands or with the lifted leg. One-leg standing time continued until the supporting leg position became misaligned during One-leg standing or a part of the body other than the supporting leg touched the ground. Pre, post, and Post2.5MO times were compared.

2.3.7. Functional Reach Test (FRT)

FRT was measured with reach of both hands blocking trunk rotation. Reflective markers were attached to subjects' right wrists. From a standing position with legs opened freely, subjects elevated both arms 90˚ forward and this was taken as the starting point. We measured forward reach of the hands from this point with subjects bending their trunks forward. We measured maximum forward reach distance with no movement of the feet or legs. Subjects held each standard position for 3 seconds and data was uploaded into three-dimensional movement analysis equipment (Cortex, Motion Analysis Corp., Santa Rosa, CA). Maximum reach length (difference between maximum reach position and starting position) was trialed 3 times and Pre, Post, and Post2.5MO measurements were compared.

2.3.8. Minimum Foot Clearance (MFC)

Three-dimensional motion analysis equipment was used to measure MFC. Reflective markers were attached to subjects' hips, knees, ankles, second metatarsal bone and calcaneal region. Subjects' right legs were measured. Subjects walked 3 times over a level 25 meter measurement path at their usual speed. MFC was considered to be the height of the second metatarsal bone from the floor while the right leg was elevated. Measurements were taken 3 times and the mean values of these 3 measurements were used for our analysis. Pre, Post, and Post2.5MO MFC values were compared (**Figure 2**).

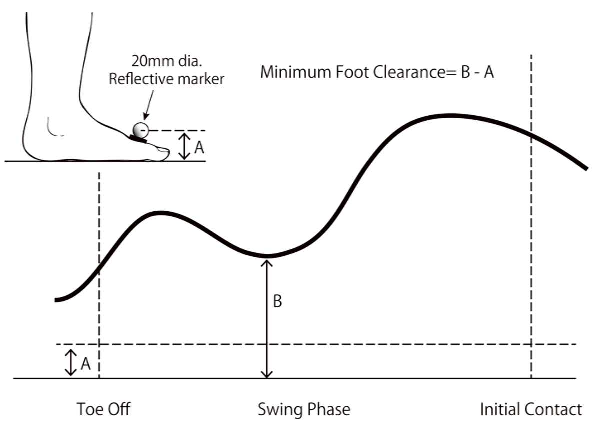

Figure 2. Minimum foot clearance is the shortest distance from the floor in the trajectory of the center of the reflective marker attached to the toe during the swing phase.

2.3.9. Statistical Methods

We performed a one-way repeated measures analysis of variance (one-way ANOVA) across 3 time points, before (Pre), after (Post), and approximately 2.5 months after (Post2.5MO) the intervention to statistically analyze the changes in each parameter with post hoc Tukey's honestly significant difference (HSD) test where appropriate.

JMP pro Ver9.0.3 (SAS Institute, Cary, NC) statistical software was used and 5% was set to indicate statistical significance.

3. RESULTS

All participants played the game 24 times or more, averaging 25.83 ± 1.81 times. Post intervention interval before the final measurement (Post 2.5MO) averaged 78.48 ± 8.81 days. No subjects quit the study.

3.1. Isometric Muscle Strength

Isometric hip joint flexion strength significantly increased by 27% immediately after the exergame intervention ($p = 0.0004$), but decreased significantly after the post intervention interval returning to the level almost equivalent to the base line (Post2.5MO) ($p < 0.0001$).

Knee extension strength exhibited a significant difference significantly increased by 22% immediately after the exergame intervention differences between Pre and Post ($p = 0.0051$) and Post and Post2.5MO ($p = 0.0021$) Knee flexion strength exhibited a significant difference between Pre and Post ($p = 0.0001$) and Post and Post2.5MO ($p = 0.0002$) values, with an improvement Pre and Post of 40%. However, no significant differences were observed between Pre and Post2.5MO values. For ankle dorsiflexion strength exhibited a significant difference between Pre and Post ($p = 0.0414$) values, with an improvement of 15%. And, significant differences were observed between Pre and Post2.5MO ($p = 0.0055$) and Post and Post2.5MO ($p < 0.0001$) (**Table 3**).

3.2. Performance Test

3.2.1. One-Leg Standing Time

There was no improvement or deterioration in the One-leg standing time after the exergame intervention as well as after post intervention interval (**Table 4**).

3.2.2. FRT

There was no improvement or deterioration in the FRT after the exergame intervention as well as after post intervention interval (**Table 4**).

3.2.3. MFC

Mean foot clearance during the swing phase significantly increased by 9.52 mm in average after the exer-

Table 3. Comparison of muscle force at baseline. After exercise intervention and 2.5 month after exercise intervention.

Variable	Pre	Post	Post2.5MO	*F* values*1	p values*1	p values*2 Pre vs Post	p values*2 Pre vs Post2.5MO	*p* values*2 Post vs Post2.5MO
Hip flexion (%kgBW)	25.95 (10.22)	33.84 (11.68)	27.29 (8.47)	3.979	0.023	0.0004	0.7253	<0.0001
Knee extension (%kgBW)	35.29 (13.16)	43.15 (16.74)	33.53 (11.69)	3.151	0.049	0.0051	0.5004	0.0021
Knee flexion (%kgBW)	20.91 (8.81)	29.27 (11.31)	21.99 (6.64)	5.897	0.004	0.0001	0.5998	0.0002
Ankle dorsiflexion (%kgBW)	26.80 (7.89)	30.81 (8.62)	21.73 (6.45)	8.138	0.001	0.0414	0.0055	<0.0001

Values are mean (standard deviation). *1one-way ANOVA, *2Tukey's post-hoc test.

Table 4. Changes in one-leg standing time, functional reach test, and minimum foot clearance before, after and 2.5 months after exercise intervention.

Variable	Pre	Post	Post2.5MO	*F* values*1	p values*1	p values*2 Pre vs Post	p values*2 Pre vs Post2.5MO	*p* values*2 Post vs Post2.5MO
One leg standing Time (sec)	29.28 (18.85)	29.83 (19.73)	33.01 (20.12)	0.240	0.787	-	-	-
Functional reach test (cm)	27.6 (5.12)	30.74 (3.98)	30.04 (5.71)	2.638	0.079	-	-	-
Minimum foot clearance (mm)	40.525 (7.17)	50.05 (8.17)	39.28 (9.58)	4.916	0.015	0.0445	0.9406	0.021

Values are mean (standard deviation). *1one-way ANOVA, *2Tukey's post-hoc test.

game intervention (p = 0.0445). but decreased significantly after the post intervention interval returning to the level almost equivalent to the base line (Post2.5MO) (**Table 4**).

4. DISCUSSION

Another intervention study using video games for elderly subjects reported on cognitive function effects [9,18,19], but few reports have investigated changes in muscle strength [20,21]. This could be because many of these studies involved subjects operating controllers with their fingers while watching a video game screen. The appearance of the low-priced and easy-to-use Kinect™ device will likely lead to the development of exergames that involve subjects moving their bodies in the future.

Exergames in which people move their bodies could be used to improve motor function in the elderly just like regular exercise. Furthermore, the fact that no subjects dropped out partway through this study and that video game training can reportedly increase motivation [3,4,22] suggest that exergames could help people continue to engage in exercise.

Here we confirmed improved leg muscle strength and increased MFC in elderly individuals who engaged in an exergame approximately 24 times. The muscle groups in which improved strength was observed included the hip flexion muscles and ankle dorsiflexion muscles, which are necessary for maintaining clearance in early leg lift during walking [23,24]. Walking patterns with low walking clearance have also been reported as strong risk factors for trip-related falls as the toes touch the ground in the early leg lift period during walking [23]. During normal walking, the hip flexion muscle group is used in the activity period extending from the standing late period to early leg lift period. When speed increases, the activity start period happens earlier and the activity period is extended. This suggests that improving hip flexion strength improves the leg step out moment in the early leg lift period, which consequently improves MFC. The exergame in the present study appeared to not only improve the muscle strength of elderly individuals but also their walking style.

However, playing the game did not lead to any differences in One-leg standing time and FRT. One-leg standing time appeared to be due to the fact that subjects were allowed to use a T-cane while playing Leg game because one subject fell over when first beginning the game; the use of a T-cane may have led to insufficient pure One-leg standing exercise load. However, as risk management is of extremely high priority in exercise for the elderly, it appeared that our efforts to achieve a balance with risk in the game that we developed led to no effects being observed for One-leg standing time. Furthermore, exercise volume tended to increase as the elderly subjects became more engrossed in the game. Therefore, we determined that we need to design game contents that offer the greatest effects, while also taking risk management into consideration.

Moreover, compared the balance function effects of exercise with a Wii Fit™ (Nintendo Co., Ltd. Redmond, WA) alone, exercise guidance by an actual physiotherapist, and a combination between the Wii Fit™ and a physiotherapist and found that greater effects were achieved by exercise guided by a physiotherapist also using the Wii Fit™ than with the Wii Fit™ alone. This suggests that exergames remain a tool for enjoying exercise although effects may be limited when operated by users alone [25].

If elderly individuals could easily operate exergames at facilities or at home, the exercise frequency of elderly individuals could be increased without increasing the burden on surrounding staff. A system such as this could help to maintain and improve motor function in elderly individuals.

Limitations of the Study

The mean subject MFS score of 11.33 ± 2.26 in this intervention study suggested that our subjects were elderly individuals with relatively high exercise ability. Therefore, it cannot be determined whether engaging in the game that we developed directly contributes to a decreased rate of falls in the elderly, especially those with frailty or sarcopenia who are at a higher risk of falls. In addition this study was a one-arm study without a control group. Considering the returning of muscle strength and foot clearance to the baseline after post intervention interval of more than 2.5 months, however, suggests the improvement in exercise performance was induced by the frequent participation in the exergame. A randomized controlled study is required to confirm the effect of exergame involving whole body movement.

5. CONCLUSION

Exergames are video games that are operated by people moving their bodies. We confirmed that exergames could be used to improve the exercise functions such as muscle strength and walking parameters in the elderly. As video games can be used to continuously, simply, and frequently engage in exercise, they may be a highly useful tools for maintaining exercise function in the elderly.

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