Original Article

Effects of Short-Term Training of Community-Dwelling Elderly with Modular Interactive Tiles

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Abstract

Objective: The objective of this study is to test for the increased mobility, agility, balancing, and general fitness of community-dwelling elderly individuals as a result of short-term training involving playing with modular interactive tiles (Entertainment Robotics, Odense, Denmark) at two community activity centers for the elderly. Three different tests from the Senior Fitness Test were used in order to test a variety of health parameters of the community-dwelling elderly, including those parameters related to fall prevention.

Materials and Methods: Eighteen community-dwelling elderly individuals (63–95 years of age; mean, 83.2 years of age) were assessed in one intervention group without the use of a control group. The intervention group performed nine group sessions (1–1.5 hours each) of playful training with the modular interactive tiles over a 12-week period in two community activity centers for the elderly. Data were collected using pre-tests and post-tests of the 6-Minute Walk Test (6MWT), the 8-foot Timed Up & Go Test (TUG), and the Chair-Stand Test (CS). Data were analyzed for statistically significant differences and increases of means.

Results: The 6MWT, TUG, and CS measurements showed statistically significant differences and increases of means between the pre-tests and post-tests with the 6MWT ($P < 0.001$) (means difference, 22.4 percent), TUG ($P < 0.001$) (means difference, 15 percent), and CS ($P < 0.002$) (means difference, 14 percent). Fifty-six percent of the elderly progressed from one health risk level to a better level, according to the three tests.

Conclusions: Statistically significant increases in scores were found across all tests, suggesting an improvement of many different health parameters for the elderly. Well-established research has shown the relationship between such test scores and fall incidents, balancing, mobility, agility, etc. This significant improvement in the health status of the elderly is obtained in as few as nine training sessions over a 12-week period of ''playing'' exergames with the modular interactive tiles.

Introduction

THE CURRENT LITERATURE SHOWS that exercise can have many health benefits. For instance, exercise may help prevent falls in older people.[1,2] Physiological risk factors for falls include reduced leg strength, impaired vision, slowed reaction time, poorer peripheral sensation, and greater sway.[3] Specific exercises can be used to modify some of these risk factors. For instance, various components of aerobic fitness have been linked to increased functional ability and activities of daily living.[4,5] Conversely, decreased functional ability and activities of daily living have been linked to falls.[6]

In order to motivate people to perform exercises that have these health benefits, game platforms with physical games, also known as exergames or active videogames, have been investigated as exercise tools. One of the better-known exergames is the Nintendo (Kyoto, Japan) Wii™ system with ''Wii Fit,'' ''Wii

Cardio,'' or ''Wii Sports.'' In addition, other exergames have been investigated, such as ''Dance Dance Revolution'' (Konami Digital Entertainment, El Segundo, CA), Sony (Tokyo, Japan) PlayStation™ 2 EyeToys™ games, and Microsoft (Redmond, WA) Kinect™ games. These platforms are all screen-based, with videogames running on the screen and users activating the games by producing physical actions in the room in front of the screen. In the process, attention is directed toward the screen while the physical actions are being performed.

However, even if indications exist,[7] further evidence of health effects from playing exergames is needed. For instance, Wollersheim et al.[8] showed that despite significant energy expenditure, there were no substantial physical effects among elderly women playing the Nintendo Wii in their study. Most quantitative effect studies have focused on energy expenditure (along with heart rate and oxygen consumption) that occurs in smaller bursts when playing the games, perhaps because of an

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initial interest in exergames as a potential tool for weight loss. These studies were able to demonstrate differences in energy expenditure between games (see the meta-analysis of Peng et al.[9]), but evidence of effects on the general physical condition (body weight, balancing, mobility, agility, strength, etc.) of the subjects is still needed.

Reviews of the literature concluded that energy expenditure ''while playing the Wii was not greater than brisk walking.''[10, p.1173] Some studies showed limited or no effect in recognized tests of fitness, mobility, agility, balancing, etc.,[11,12] although some exceptions were found with very specific patient groups (see, e.g., Gil-Gómez et al.[13] and Saposnik et al.[14]). Indeed, Lange et al.[15] and Taylor et al.[16] outlined that more rigorous standard treatments, comparisons, and tests are needed, especially for effect studies among adult subjects, in order to evaluate the potential of exergames as a general training and therapeutic tool beyond training for obese youth (e.g., as concluded in the review by Wiemeyer and Kliem[17] of serious games for use in prevention and rehabilitation among elderly people).

In terms of fall prevention training, research has suggested that recruiters for interventions sometimes recruit subjects who have too low a risk of falling and that there is a need to target those likely to benefit the most. Barnett et al.[18] indicated that those who are likely to benefit the most are older people with strength and balance deficits, women 80 years of age and over, and those 70 years of age and over with one or more fall risk factors. For instance, in their study with 37 group exercise sessions over a year in a community setting, they found improved balance and a reduced rate of falling among at-risk community-dwelling older people. However, the same study[18] showed no improvement in walking speed and sit-to-stand time, although Lord et al.[19,20] found improvements in previous studies that used a more frequent program (more sessions per week) with higher dosage. Therefore, it may be interesting to study whether or not the more frequent program with a high dosage of training is a necessity in order to see improvement in balancing, walking speed, and sit-to-stand time among at-risk community-dwelling older people. Hence, here, we will investigate the effect of short-term playful training with modular interactive tiles among the elderly.

These modular interactive tiles[21] are used by therapists to provide treatment for a large number of patients who receive hospital, municipality, or home care interventions, but the tiles can also be used for prevention with the elderly or for fitness with the general population. Nielsen and Lund[22] described the use of the modular interactive tiles with cardiac patients, smoker's lung (chronic obstructive pulmonary disease) patients, and stroke patients in hospitals and in the private homes of patients and the elderly and showed that therapists were using the modular aspect of the tiles for a variety of personalized training, while modulating exercises and difficulty levels. Such personalization through modulation of exercises and difficulty levels may allow the system to be used for playful training also among community-dwelling elderly with diverse levels of functional abilities, as will be tested in the present study.

Materials and Methods

The modular interactive tiles[21] (Entertainment Robotics, Odense, Denmark) are a distributed system of electronic tiles that, like building blocks, can be attached to one another to form the overall system (Fig. 1). Each tile is self-sufficient in terms of processing power, and each one has a battery that lasts for approximately 30 hours of use. This makes the usage of the tiles very flexible because the tiles do not need a computer, a computer monitor, or an external power source. When connected to one another to form a playfield, the modular tiles communicate to their neighbors through four infrared transceivers located on the sides. One tile has an XBee radio communication chip, with which it can communicate to other devices that also have an XBee chip, such as a game selector box or a personal computer that has an USB XBee dongle connected.

When playing on the tiles, the subject provides the tiles with input in the form of pressure, which is measured by a force-sensitive resistor that is located in the center of each tile. The tile can then react by turning on eight RGB light-emitting diodes that are mounted with equal spacing between each other in a circle inside the tile. Table 1 shows the technical specifications of a modular tile.

Tests

The Senior Fitness Test[23] has validated fitness standards (performance cut points) associated with having the ability to function independently among more than 2000 older adults, and these cut points' accuracy and consistency have been validated as predictors of physical independence. Each individual subject's score can be classified into one of four levels (above average, normal range, below average, or low functioning) on each of the individual tests of the Senior Fitness Test (e.g., the 6-Minute Walk Test [6MWT], the Chair-Stand Test [CS], and the Timed Up & Go Test [TUG]) and can be used to assess the individual's health risk level. Three different tests from the Senior Fitness Test[23] have been found to be useful and well established for testing a variety of health parameters related to health risk prevention, such as mobility, agility, balancing, and general fitness, in community-dwelling elderly. These tests include the 6MWT, the 8-foot TUG, and the CS.

It has been shown that the 6MWT can be used as a fall risk indicator specifically for frail elderly.[24] Furthermore, it has been shown that the 6MWT not only measures aerobic fitness and mobility, but also incorporates components of leg strength, balance, reaction time, and vision.

The TUG provides a measure of functional mobility[25] and reflects a combination of sensory, motor, and strength abilities.[26] The TUG has also been shown to be a tool for discriminating between future fallers and nonfallers.[24] The 8-foot version of TUG has been demonstrated to have similar qualities for agility and dynamic balancing and is a reliable test for predicting future fallers and nonfallers from among the community-dwelling elderly population.[27]

The CS provides a measure of lower body strength and endurance, and it has been shown that the CS is a reliable and valid indicator of lower body strength in generally active, community-dwelling older adults.[28]

Intervention

Elderly individuals at two senior community activity centers in Gentofte (Copenhagen), Denmark, were offered the opportunity to participate in playful training with the
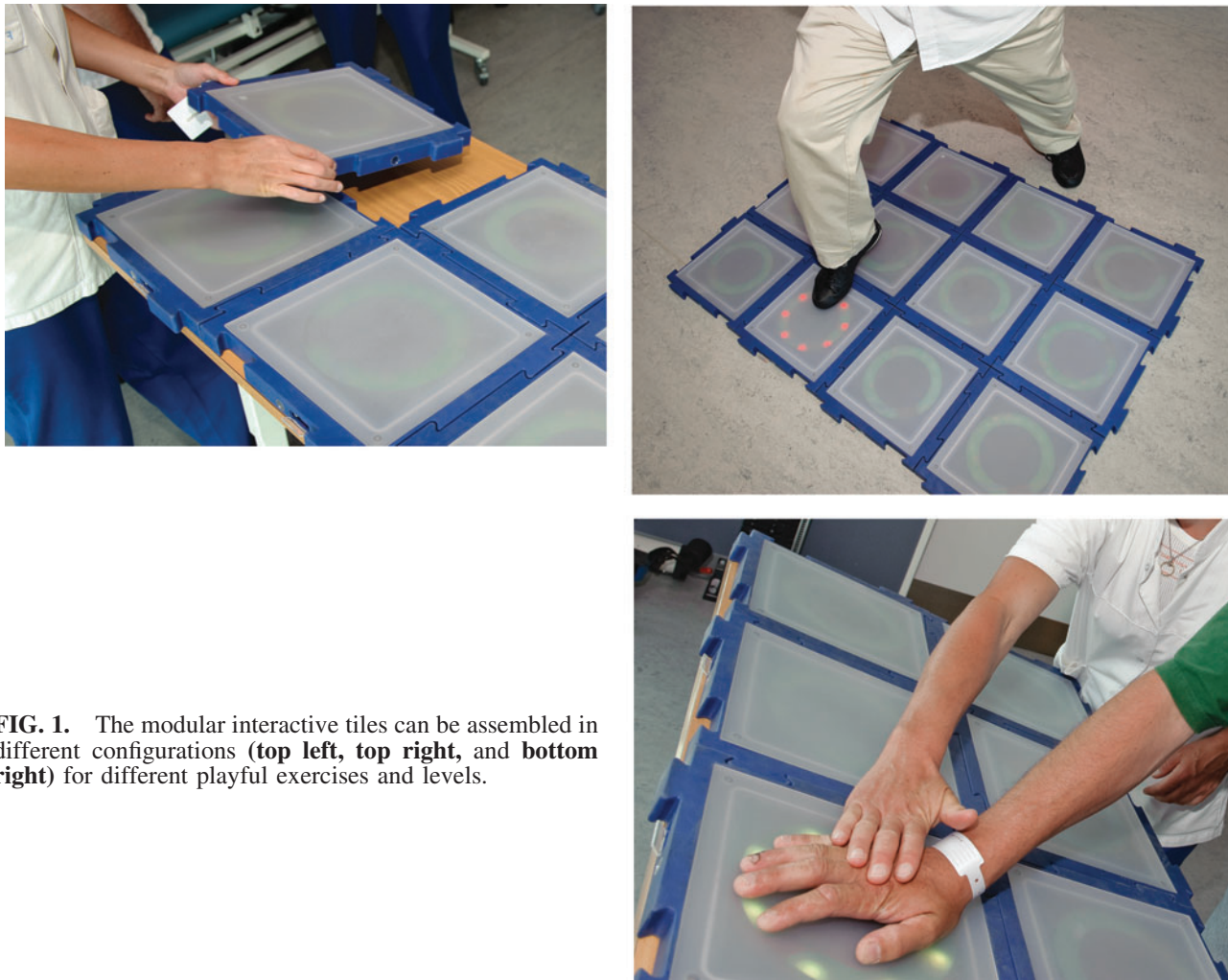
FIG. 1. The modular interactive tiles can be assembled in different configurations (**top left, top right,** and **bottom right**) for different playful exercises and levels.

modular interactive tiles once a week for 12 weeks. The senior community activity centers are organized so that most elderly individuals are transported to the centers from their private homes once or twice a week to engage in center activities for social interaction, and the elderly participants were offered the opportunity to participate in training with the tiles as part of these center activities.

Gentofte Municipality had the study approved by the ethics committee, and the participants signed letters of informed consent to participate. Eighteen elderly individuals 63–95 years of age (mean, 83.2 years of age) participated in the training (Table 2). Tests (CS, TUG, and 6MWT) were performed before and after the intervention (pre- and post-tests, respectively). The intervention group performed nine group sessions of training with the modular interactive tiles once a week over a 12-week period (there were a few break

TABLE 1. TECHNICAL SPECIFICATION OF A MODULAR INTERACTIVE TILE

Description	Amount	Type
Processor	1	ATmega1280
Sensor	1	FSR
Sensor	1	Two-axis accelerometer
Effector	8	RGB color LEDs
Communication	4	IR transceivers
Communication	1	XBee radio chip
Energy	1	Li-Io polymer battery
Switch	1	On/off switch
Connector	4	Jigsaw puzzle
Size	$300 \times 300 \times 33$ mm	
Weight	1 kg	

IR, infrared; LED, light-emitting diode.

TABLE 2. CHARACTERISTICS OF THE INTERVENTION GROUP

Parameter	Value
Age (years)	83.2 (63–95)
Gender	3 males/15 females
Height (m)	1.70 (1.50–1.80)
Weight (kg)	70.1 (52.6–106.5)
BMI (kg/m^2)	25.5 (18.48–31.99)

Data are average (range) values.
BMI, body mass index.

TABLE 3. RESULTS OF PRE-TEST AND POST-TEST OF THE NINE SESSIONS OF TRAINING WITH MODULAR INTERACTIVE TILES

Test	Pre-test (σ)	Post-test (σ)	Average improvement (percent)	Significance level	Level improvements
CS	9.9 (2.6)	11.3 (3.1)	14	$P < 0.002$	7
TUG	11.0 s (6.1)	9.4 s (4.9)	15	$P < 0.001$	6
6MWT	247.6 m (82.0)	303.0 m (106.3)	22.4	$P < 0.001$	7

6MWT, 6-Minute Walk Test; CS, Chair-Stand Test; TUG, Timed Up & Go Test.

weeks in the weekly sessions due to holiday breaks). Each session lasted 60–90 minutes, and each individual would be engaged in active play on the tiles for 10–15 minutes per group session. A research assistant would guide the group's training on the modular interactive tiles, using 10–12 tiles for each session.

During part of the session, the tiles would be split into two smaller platforms (with five or six tiles each) to allow for parallel interaction of two individuals on two different platforms. Another part of the session would occur on a larger platform of tiles, on which the participants would interact individually or in pairs on competitive games.

The games used for the training included "Color Race," "Final Countdown," "Reach," "Island Game," "Concentration Game Color," and "Simon Says."[29] The latter two games are memory games that may potentially challenge both physical and mental skills, whereas the first four games are further challenging mobility, balancing, endurance, and reaction. Most games are designed to challenge several physical and cognitive abilities simultaneously while the individuals are playing the games.

Statistical analysis

Data were collected from pre- and post-tests. The average score and standard deviation were calculated, and the Wilcoxon Signed-Rank Test was used to test for statistically significant differences between the pre- and post-tests. The Wilcoxon Signed-Rank Test was selected because the population of community-dwelling elderly was expected to exhibit a high variance in functional abilities. Therefore a normal distribution of the population's test scores cannot be assumed. The Wilcoxon Signed-Rank Test is a statistical hypothesis test suitable under such circumstances.

Results

Sundhedsdoktoren, an independent third party that was not involved with the training, conducted the pre- and post-tests. The post-test was performed blinded from the pre-test results. The tests were conducted in the two senior community activity centers.

The results of the pre- and post-tests are presented in Table 3. All of the tests showed a statistically significant improvement of performance between the pre-test and post-test at levels of $P < 0.001$ or $P < 0.002$ (by Wilcoxon Signed-Rank Test). The average improvement was 14 percent on CS, 15 percent on TUG, and 22.4 percent on 6MWT. Furthermore, several subjects improved so that they transferred from one health risk level to another health risk level (according to the criterion reference points of Rikli and Jones[23]), improving at least one level (seven subjects improved their level according to the CS results, six subjects improved their level according to the TUG results, and seven subjects improved their level according to the 6MWT results). In total, 56 percent of the subjects improved their health risk level according to at least one of the tests.

As confirmed by the quantitative data, the qualitative observations also found the subjects to be much more mobile at the post-test. For instance, it was found that three of the subjects who performed the pre-tests with the use of orthopedic aids (rollator, walker, or cane) performed the post-test without these aids or completed the post-test using the aids far less than they used them during the pre-test.

Discussion

Research has suggested that a high dose of exercise is needed to obtain significant effects on the fall rates, gait speed, and other indicators of health in the elderly population. The review and meta-analysis by Sherrington et al.[2] suggest that a high dose of exercise (> 50 hours) is needed for greater relative effects of exercise on fall rates. Also, the meta-analysis of Lopopolo et al.[30] found that high-dosage intervention had a significant effect on the gait speed of community-dwelling elderly, and it found no effect for low-dosage exercise. (Gait speed is an important measure because there is evidence of correlation between gait speed and mortality.[31])

However, it is noteworthy that significant change is found, for example, in gait speed, among the elderly who performed low-dosage playful training with modular interactive tiles after merely nine sessions. In our study, there is a large increase (22.4 percent) in gait speed from 0.687 m/second in the pre-test to 0.841 m/second in the post-test, when calculated using the 6MWT. This is a large increase compared with other studies, such as the meta-analysis by Lopopolo et al.[30] of the effect of therapeutic exercise on gait speed in community-dwelling elderly. This occurs despite the fact that their meta-analysis suggested that a high dosage is necessary to obtain greater improvement. The relatively high levels of improvement in our study may be due to the fact that the elderly individuals in our study are somewhat frail, with a pre-test gait speed of 0.687 m/second, so the nine sessions of training with the modular interactive tiles may be sufficient to invoke change in muscle force-production and gait speed.

The result of low-dosage playful training on modular interactive tiles shows that the subjects improved on all three tests, and hence they improved on a large variety of physiological abilities. These abilities may include aerobic fitness, mobility, reaction time, balancing, endurance, and strength. It is interesting that this kind of playful training on the modular interactive tiles can lead to such a general improvement of functional abilities because other training methods often improve the subjects' abilities only partly.

One such method is the combined stretching, balance, and strengthening exercises method of DiBrezzo et al.,[32] presented in a study that in many of the set-up parameters is comparable to the study that we present here with the modular interactive tiles. The study by DiBrezzo et al.[32] was performed over a period of time that was similar to our study (10 weeks), with a similar population (16 community-dwelling elderly individuals 60–92 years of age [average, 74.9 years of age]), in similar settings (two local senior community centers), and with similar evaluation procedures (pre- and post-test using the Senior Fitness Test, including the [8-foot] TUG, CS, and 6MWT). However, over the 10-week period, the participants performed 30 sessions (1 hour per session) of stretching, balance, and strengthening exercises in the study by DiBrezzo et al.[32] After the 30 sessions, they found statistically significant improvements on CS ($P < 0.01$) and TUG ($P < 0.001$) but no significant improvement on the 6MWT.

Our study was different than the study by DiBrezzo et al.[32] in that we included slightly older subjects (average age, 83.2 versus 74.9 years) who performed much fewer training sessions (9 versus 30 training sessions) and obtained statistically significant improvements on all three tests: CS ($P < 0.002$ versus $P < 0.01$), TUG ($P < 0.001$ versus $P < 0.001$), and 6MWT ($P < 0.001$ versus difference not significant).

It is also interesting to compare the results received in this research with the potential results of other exergames and to try to analyze why the training with the modular interactive tiles appeared to be effective for the present short-term intervention. This information can be helpful in order to understand how to create effective exergaming and training. In comparison with the use of the ''Wii Fit,'' the study with the modular interactive tiles shows a noteworthy difference in the subjects' performance on the standard tests. Franco et al.[11] obtained no significant effect on standardized balance tests (Berg and Tinetti) when community-dwelling elderly (average age, 78.3 years) individuals were exercising with the Nintendo ''Wii Fit,'' and Nitz et al.[12] showed in their study with adult subjects (age, 30–58 years) using a ''Wii Fit'' for 20 sessions that there were no improvements in the performances on the 6MWT and TUG. On the other hand, the present study with subjects using the modular interactive tiles for nine sessions showed a statistically significant performance improvement on the 6MWT and TUG.

Because of the lack of effect found in the use of the commercial exergames (such as the Nintendo Wii system) in larger health areas, the review on activity-promoting gaming systems in exercise and rehabilitation by Taylor et al.[10] arrived at the conclusion that a ''potential limitation of the available commercial games and gaming systems, even though they encourage improvements in balance, strength, and fitness, is that they are not necessarily designed for rehabilitation.''[10,p.1183]

Indeed, the presented study suggests that exergames designed specifically for prevention and rehabilitation can have a significant effect in a fast manner. With the modular interactive tiles and the games that were designed specifically as exergames for enhancing physiological and cognitive abilities in a playful way, it is possible to observe significant effects. The design was targeted the health area and with prevention and rehabilitation in hospitals, care and rehabilitation institutions, and private homes in mind, and this focus led to the development of a platform that is easy to adapt to health interventions, to individual levels, to progressive levels, and to different environments.

This kind of exergaming design of hardware and software targeting prevention and rehabilitation can be exemplified with the exergaming design for falls prevention. The systematic review and meta-analysis by Sherrington et al.[2] found that the greatest effect of training on reducing falls was obtained from programs that challenged balance to a high extent. They showed that ''moderate- or high-intensity strength training was not found to be associated with greater effect of exercise on falls,'' that ''exercise programs that did not include walking reduced fall rates more than did exercise programs that involved walking,'' but that ''inclusion of balance training in exercise programs appears to be important.''[2,p.2241] Furthermore, the Cochrane review by Gillespie et al.[1] found that multifaceted interventions can prevent falls in the general community, in those at greater risk, and in residential care facilities.

With this important knowledge in mind, we designed a technology that challenges balance in a multicomponent way when the subjects are playing physically interactive games on the modular interactive tiles. Each of these physically interactive games simultaneously challenges many components of the subjects' physical and cognitive abilities. The modular interactive tiles games enforce activities that combine physical training with sensory tasks and cognitive tasks. Some of the games are consequently designed to promote unpredictable, sudden movements, and the games allow for a gradual increase of difficulty. Even the modularity of the tiles allows games to progressively change level merely by changing the physical platform.[22]

In her review, Shubert[33] concluded that home exercise programs should be structured, be progressive, incorporate different components for balance training, and increase in difficulty in order to challenge the patient's skills (e.g., vary exercises for even greater challenges). With the simple adaptivity to a patient's level done by changing the physical platform (e.g., putting a few less or a few more modular tiles in the platform) or by changing the game level by swiping a new game card with a different level, the modular interactive tiles and their games seem to be suitable for such home exercise programs. The intervention presented here can be viewed as an initial training that quickly improves the performance of the elderly, and it seems feasible to continue the exercise on modular interactive tiles with different games and levels or over a longer period of time afterward to create a longer duration intervention for patients at risk of falling or at risk for other significant health issues. An important aspect of a longer continuation of training is that users find the playful exercises with modular interactive tiles to be highly motivational and fun.[21,22]

In conclusion, compared with related work on effect studies of general fitness interventions (e.g., strength training, aerobics, cycle and circuit resistance training, balancing training, walking, Tai Chi, etc.) for community-dwelling elderly, which show significant effects on only a selected set of health parameters, surprisingly, this study demonstrates significant improvements on all tests after short-term training with the modular interactive tiles. It also shows a high level of improvement in gait speed. It is noteworthy that significant effects were obtained on all of the tests performed and

that significance was obtained after just nine playful training sessions with the modular interactive tiles. This effect was found despite prior literature noting that many more sessions are needed with the traditional training in order to obtain any effects. The results presented here show that exergaming can have a large effect on community-dwelling elderly individuals when they are training in a playful manner with the modular interactive tiles.

Acknowledgments

Author Disclosure Statement

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