

Original Paper

Effect of a Kinect-Based Exercise Game on Improving Executive Cognitive Performance in Community-Dwelling Elderly: Case Control Study

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Abstract

Background: Decrease of dual-task (DT) ability is known to be one of the risk factors for falls. We developed a new game concept, Dual-Task Tai Chi (DTTC), using Microsoft's motion-capture device Kinect, and demonstrated that the DTTC test can quantitatively evaluate various functions that are known risk factors for falling in elderly adults. Moreover, DT training has been attracting attention as a way to improve balance and DT ability. However, only a few studies have reported that it improves cognitive performance.

Objective: The purpose of this study was to demonstrate whether or not a 12-week program of DTTC training would effectively improve cognitive functions.

Methods: This study examined cognitive functions in community-dwelling older adults before and after 12 weeks of DTTC training (training group [TG]) or standardized training (control group [CG]). Primary end points were based on the difference in cognitive functions between the TG and the CG. Cognitive functions were evaluated using the trail-making test (part A and part B) and verbal fluency test.

Results: A total of 41 elderly individuals (TG: n=26, CG: n=15) participated in this study and their cognitive functions were assessed before and after DTTC training. Significant differences were observed between the two groups with significant group $\times$ time interactions for the executive cognitive function measure, the delta-trail-making test (part B-part A; $F_{1,36}=4.94$, $P=.03$; TG: pre mean 48.8 [SD 43.9], post mean 42.2 [SD 29.0]; CG: pre mean 49.5 [SD 51.8], post mean 64.9 [SD 54.7]).

Conclusions: The results suggest that DTTC training is effective for improving executive cognitive functions.

Trial Registration: Japan Medical Association Clinical Trial Registration Number: JMA-IIA00092; <https://dbcentre3.jmacct.med.or.jp/jmactr/App/JMACTRS06/JMACTRS06.aspx?seqno=2682> (Archived by WebCite at <http://www.webcitation.org/6NRtOkZFh>).

(*J Med Internet Res* 2014;16(2):e61) doi:[10.2196/jmir.3108](https://doi.org/10.2196/jmir.3108)

KEYWORDS

fall prevention; cognitive function; dual-task; training; elderly

Introduction

Cognitive impairment among elderly individuals is a serious issue in many countries. Many investigators have developed different cognitive function training methods as countermeasures to prevent cognitive impairment and have reported their effects [1]. Other investigators also have reported the effects of physical exercise training on cognitive functions among elderly individuals [2,3]. Additionally, Hillman et al and Silsupado have indicated that executive cognitive functions, which are related to the control of goal-oriented actions and adaptive behaviors, are strongly impaired by aging and respond positively to exercise training [4,5].

Recently, dual-task (DT) ability, or the performance of simultaneous motor and cognitive tasks, has been receiving considerable attention [6]. DT training is now recognized as a fall prevention tool that enhances physical functions among elderly people [7].

With a focus on DT, we developed a new concept called the Dual-Task Tai Chi (DTTC) test [8]. This system was developed using Kinect (Microsoft, Redmond, WA, USA), a motion-capture device, and demonstrated that the DTTC test quantitatively evaluates compound functions, including DT, balance, and cognitive abilities in elderly people [9]. In unpublished data, we found that DTTC training was useful not only to assess but also to improve balance and mobility among elderly people [10].

Several investigators have reported the effects of DT training on balance, mobility, walking, and DT ability [11,12]. However, only a few have reported that DT training improves cognitive performance. We reported that Trail-Walking Exercise, which is similar to Trail-Making Test (TMT) under DT condition, improved executive cognitive functions [13]. According to this, we expected that DTTC training would improve cognitive functions as well, especially executive functions. Therefore, the purpose of this study was to reveal that training with the DTTC device affects cognitive performance in elderly individuals.

Methods

Participants

Community-dwelling elderly subjects (n=48) participated in this study. The subjects were recruited through an advertisement in the local press. The following selection criteria were used: age ≥ 65 years, community dwelling, independent ambulation, willingness to participate in the measurement of physical fitness, and minimal hearing and vision impairment. Exclusion criteria were as follows: inability to complete the tasks because of reduced cognitive functions, evaluated by Rapid Dementia Screening Test [14] scored 8 or greater; severe cardiac, pulmonary, or musculoskeletal disorders; pathologies associated with increased risk of falls, such as Parkinson's disease or stroke; osteoporosis; and psychotropic drug use. We obtained written informed consent from each participant. This study was approved (protocol approval E- 880) by the Ethical Review Board of Kyoto University Graduate School of Medicine, Kyoto, Japan.

Device

The DTTC test [8-10] requires users to solve a number placement problem (Sudoku) by controlling a stick figure with the movement of their entire body. The user's full-body motion is captured using Kinect and is translated into movements for the stick figure on a screen. The cognitive task is to fill in 3 boxes chosen at random from a 4×4 grid with digits ranging from 1 to 4. The user selects a digit using his or her right hand and left foot and points to a box with his or her left hand. In addition, the user must move his or her right hand to the left hand to fill the indicated box with the selected digit. As such, full-body motion, similar to Tai Chi Chuan movements, is required. We recorded the time taken to fill in all 3 boxes, as our evaluation index.

To begin with, the user stands 3 m in front of the Kinect sensor with his or her right foot in front of the sensor (Figure 1). The following instructions were provided:

1. Reach a digit you need to use with your right hand to fill a blank you want to answer.
2. Step 50 cm laterally, with your left leg, to grip the digit in your right hand.
3. Select the blank you want to answer with your left hand, and move your right hand to your left one.

The diagram illustrates a human-machine interaction system. On the left, a large blue rectangle labeled "SCREEN" displays a 4x4 grid of numbers. The grid is as follows:

4	3	2	1
4	2	3	4
3	1	4	2
2	4	1	3

The cell containing the number "2" in the second row, first column is highlighted with a red square. A green line traces a path from this cell, through the "3" in the third row, second column, and the "1" in the fourth row, third column, ending at a red circle on the screen. To the right of the grid, the numbers 1, 2, 3, and 4 are listed vertically. Below the screen is a "Kinect sensor" represented by a grey trapezoid with a green circle. A "PC" (laptop) is connected to the Kinect sensor. On the right, a person in a light blue hoodie and dark pants is shown from behind, in a dynamic pose. Three orange lines connect the person's movements to the screen: line ① points to the top right, line ② points to the bottom right, and line ③ points to the top left. The person's hands are labeled with circled numbers ① and ②.

We compared baseline characteristics between the participants in each group to examine the comparability between the 2 groups using Student's *t* test or the chi-square test. Repeated-measures, mixed-linear, two-way ANCOVA (analysis of covariance) was used to analyze the effect of exercise on

outcome measurements while adjusting for each cognitive performance, at pre-intervention, as a covariate.

Data were entered and analyzed using the Statistical Package for the Social Sciences (Windows version 20.0, SPSS Inc., Chicago, IL, USA). For all analyses, $P < .05$ was considered statistically significant.

Results

Study Population

A total of 41 of the 48 selected subjects (85.4%) completed the study protocols and returned for their exit interviews and final testing (TG: $n=26$, CG: $n=15$). The participants' baseline data did not differ significantly between the two groups. Thus, the groups were comparable and well matched with regard to their baseline characteristics.

Adherence to the Study Protocols

During the 12-week intervention phase, 10 exercise sessions were scheduled and all took place. Excluding the 4 participants who dropped out, the TG subjects had an overall attendance rate of 82% and the CG subjects had an overall attendance rate of 81% over the 12 weeks. No health problems, including cardiovascular or musculoskeletal complications, occurred during training sessions or testing. Moreover, almost all participants seemed to have enjoyed the DTTC training. They shared many positive opinions after each session and seemed to look forward to playing DTTC once a week.

Evaluation Outcomes

Pre- and post-intervention group statistics and group $\times$ time interactions are shown in Table 1. There was a significant difference between the groups regarding the changes (intervention to baseline) in delta-TMT. There were no significant differences among the other measures.

Table 1. Outcome measures by group at pre- and post-intervention.

Measures	Pre-intervention, mean (SD)	Post-intervention, mean (SD)	Group $\times$ Time <i>F</i> value	Degrees of freedom	<i>P</i> value
VFT^a					
TG ^b	11.96 (3.55)	12.04 (3.26)	0.09	1,38	.76
CG ^c	11.38 (4.21)	11.38 (4.07)			
TMT-A^d					
TG	71.6 (23.8)	68.4 (19.9)	0.51	1,38	.48
CG	82.2 (27.1)	70.0 (15.5)			
TMT-B					
TG	120.3 (55.1)	110.4 (39.2)	2.73	1,38	.11
CG	131.8 (62.6)	134.9 (61.1)			
ΔTMT					
TG	48.8 (43.9)	42.2 (29.0)	4.94	1,36	.03
CG	49.5 (51.8)	64.9 (54.7)			

^aVFT: verbal fluency test

^bTG: training group

^cCG: control group

^dTMT: trail-making test

Discussion

Principal Findings

The delta-TMT score was significantly improved after DTTC training. The results suggested that DTTC training was effective in improving executive cognitive functions. In our unpublished data, DTTC training was useful for improving balance ability and mobility among elderly people [10]. Thus, DTTC training has the capability of improving both physical and cognitive functions. Executive cognitive functions are closely related to DT performance and are good predictors of falling [20]. Thus, an improvement in executive functions, by DTTC training, has a positive impact on DT ability and the prevention of falling.

Conversely, the TMT-A and -B scores were not significantly improved. In the TMT-A, both groups improved similarly. On the other hand, in the TMT-B, only the TG had a tendency to improve the score, while CG showed little change. That is why the score of delta-TMT in CG increased and in TG decreased. The TMT-A and -B are used to assess visual scanning, cognitive flexibility, and executive functions [17]. The delta-TMT score is considered a more accurate measurement of executive functions [21,22]. That is, the results reflect specific improvement in executive cognitive functions. The reason is that DTTC training involves executive tasks that are the control of goal-oriented actions and adaptive behaviors. Additionally, VFT was also not significantly improved after DTTC training. It includes recalling tasks as their main elements; however,

DTTC training does not involve recalling the task. This is considered the reason why the result of VFT was not significantly changed.

Previous studies reported that other “exergames,” based on Nintendo Wii Fit (Nintendo, Kyoto, Japan) or other devices, improved balance and leg muscle functions [23,24]. However, in these cases, the user needs control devices to capture motions and longer and more frequent exercise is required, compared with DTTC training, to obtain physical effects. DTTC overcomes these weaknesses and can offer comparable cognitive and physical benefits to users. Other previous studies have shown that a home-based dance device, using videogame technology, also improved the physical and cognitive parameters of fall risk in elderly people [25]. These home-based training tools are expected to increase the improvement of various functions and lead to fall prevention; our DTTC device is similar to these tools.

Limitations

There are several limitations to this study. First, the intervention effects in this study were not due solely to the DTTC training. That means the rhythmic stepping exercise involving cognitive ability in both groups also improves cognitive ability. Second, participants in both groups may have had higher motivation and interest in health issues and fall risk minimization than the general elderly population. An investigation into the effects of DTTC training on functions in frail, elderly adults is necessary, in the future.

Conclusions

In this study, the ANCOVA results of delta-TMT reveal that group $\times$ time interactions were statistically significant. They suggest that DTTC training is effective at improving executive cognitive functions in particular.

Acknowledgments

The authors thank the participants and are grateful to the department staff for helpful advice.

Conflicts of Interest

None declared.

References

1. Kueider AM, Parisi JM, Gross AL, Rebok GW. Computerized cognitive training with older adults: a systematic review. *PLoS One* 2012;7(7):e40588 [FREE Full text] [doi: [10.1371/journal.pone.0040588](https://doi.org/10.1371/journal.pone.0040588)] [Medline: [22792378](https://pubmed.ncbi.nlm.nih.gov/22792378/)]
2. Kamegaya T, Long-Term-Care Prevention Team of Maebashi City, Maki Y, Yamagami T, Yamaguchi T, Murai T, et al. Pleasant physical exercise program for prevention of cognitive decline in community-dwelling elderly with subjective memory complaints. *Geriatr Gerontol Int* 2012 Oct;12(4):673-679. [doi: [10.1111/j.1447-0594.2012.00840.x](https://doi.org/10.1111/j.1447-0594.2012.00840.x)] [Medline: [22469534](https://pubmed.ncbi.nlm.nih.gov/22469534/)]
3. Kramer A, Hahn S, Cohen N, Banich M, McAuley E, Harrison C, et al. Ageing, Fitness and Neurocognitive Function. *Nature* 1999;400:418-419. [doi: [10.1038/22682](https://doi.org/10.1038/22682)]
4. Hillman CH, Erickson KI, Kramer AF. Be smart, exercise your heart: exercise effects on brain and cognition. *Nat Rev Neurosci* 2008 Jan;9(1):58-65. [doi: [10.1038/nrn2298](https://doi.org/10.1038/nrn2298)] [Medline: [18094706](https://pubmed.ncbi.nlm.nih.gov/18094706/)]
5. Silsupadol P, Shumway-Cook A, Lugade V, van Donkelaar P, Chou LS, Mayr U, et al. Effects of single-task versus dual-task training on balance performance in older adults: a double-blind, randomized controlled trial. *Arch Phys Med Rehabil* 2009 Mar;90(3):381-387 [FREE Full text] [doi: [10.1016/j.apmr.2008.09.559](https://doi.org/10.1016/j.apmr.2008.09.559)] [Medline: [19254600](https://pubmed.ncbi.nlm.nih.gov/19254600/)]
6. Lundin-Olsson L, Nyberg L, Gustafson Y. Attention, frailty, and falls: the effect of a manual task on basic mobility. *J Am Geriatr Soc* 1998 Jun;46(6):758-761. [Medline: [9625194](https://pubmed.ncbi.nlm.nih.gov/9625194/)]
7. Yamada M, Aoyama T, Arai H, Nagai K, Tanaka B, Uemura K, et al. Dual-task walk is a reliable predictor of falls in robust elderly adults. *J Am Geriatr Soc* 2011 Jan;59(1):163-164 [FREE Full text] [doi: [10.1111/j.1532-5415.2010.03206.x](https://doi.org/10.1111/j.1532-5415.2010.03206.x)] [Medline: [21226689](https://pubmed.ncbi.nlm.nih.gov/21226689/)]
8. Okamoto H, Kayama M, Yamada M. The development of a system for the assessment of a dual-task performance based on a motion-capture device. 2012 Presented at: 9th International Conference on Disability, Virtual Reality & Associated Technologies; Sept 10 - 12, 2012; Laval, France p. 483.
9. Kayama H, Okamoto K, Nishiguchi S, Nagai K, Yamada M, Aoyama T. Concept software based on Kinect for assessing dual-task ability of elderly people. *Games for Health Journal* 2012 Oct;1(5):348-352. [doi: [10.1089/g4h.2012.0019](https://doi.org/10.1089/g4h.2012.0019)]
10. Kayama H, Okamoto K, Nishiguchi S, Yukutake T, Tanigawa T, Nagai K, et al. Efficacy of an exercise game based on Kinect in improving physical performances of fall risk factors in community-dwelling older adults. *Games for Health Journal* 2013 Aug;2(4):247-252. [doi: [10.1089/g4h.2013.0006](https://doi.org/10.1089/g4h.2013.0006)]
11. Yamada M, Tanaka B, Nagai K, Aoyama T, Ichihashi N. Rhythmic stepping exercise under cognitive conditions improves fall risk factors in community-dwelling older adults: Preliminary results of a cluster-randomized controlled trial. *Aging Ment Health* 2011 Jul 1;15(5):647-653. [doi: [10.1080/13607863.2010.551341](https://doi.org/10.1080/13607863.2010.551341)] [Medline: [21815857](https://pubmed.ncbi.nlm.nih.gov/21815857/)]

12. Melzer I, Oddsson L. Improving balance control and self-reported lower extremity function in community-dwelling older adults: a randomized control trial. *Clin Rehabil* 2013 Mar;27(3):195-206. [doi: [10.1177/0269215512450295](https://doi.org/10.1177/0269215512450295)] [Medline: [22837541](https://pubmed.ncbi.nlm.nih.gov/22837541/)]
13. Yamada M, Tanaka B, Nagai K, Aoyama T, Ichihashi N. Trail-walking exercise and fall risk factors in community-dwelling older adults: preliminary results of a randomized controlled trial. *J Am Geriatr Soc* 2010 Oct;58(10):1946-1951. [doi: [10.1111/j.1532-5415.2010.03059.x](https://doi.org/10.1111/j.1532-5415.2010.03059.x)] [Medline: [20831723](https://pubmed.ncbi.nlm.nih.gov/20831723/)]
14. Kalbe E, Calabrese P, Schwalen S, Kessler J. The Rapid Dementia Screening Test (RDST): a new economical tool for detecting possible patients with dementia. *Dement Geriatr Cogn Disord* 2003;16(4):193-199. [Medline: [14512713](https://pubmed.ncbi.nlm.nih.gov/14512713/)]
15. Buchner DM, Cress ME, de Lateur BJ, Esselman PC, Margherita AJ, Price R, et al. The effect of strength and endurance training on gait, balance, fall risk, and health services use in community-living older adults. *J Gerontol A Biol Sci Med Sci* 1997 Jul;52(4):M218-M224. [Medline: [9224433](https://pubmed.ncbi.nlm.nih.gov/9224433/)]
16. Gardner M, Robertson M, Campbell A. Exercise in preventing falls and fall related injuries in older people: a review of randomised controlled trials. *Br J Sports Med* 2000 Feb;34(1):7-17. [doi: [10.1136/bjsm.34.1.7](https://doi.org/10.1136/bjsm.34.1.7)]
17. War Department Adjutant General's Office. Manual of directions and scoring. In: *Army Individual Test Battery*. Washington DC: War Department; 1944.
18. Benton AL. Differential behavioral effects in frontal lobe disease. *Neuropsychologia* 1968 Mar;6(1):53-60. [doi: [10.1016/0028-3932\(68\)90038-9](https://doi.org/10.1016/0028-3932(68)90038-9)]
19. Nemoto T, Kashima H, Mizuno M. Contribution of divergent thinking to community functioning in schizophrenia. *Prog Neuropsychopharmacol Biol Psychiatry* 2007 Mar 30;31(2):517-524. [doi: [10.1016/j.pnpbp.2006.12.001](https://doi.org/10.1016/j.pnpbp.2006.12.001)] [Medline: [17218048](https://pubmed.ncbi.nlm.nih.gov/17218048/)]
20. Mirelman A, Herman T, Brozgov M, Dorfman M, Sprecher E, Schweiger A, et al. Executive function and falls in older adults: new findings from a five-year prospective study link fall risk to cognition. *PLoS One* 2012;7(6):e40297 [FREE Full text] [doi: [10.1371/journal.pone.0040297](https://doi.org/10.1371/journal.pone.0040297)] [Medline: [22768271](https://pubmed.ncbi.nlm.nih.gov/22768271/)]
21. Lezak MD, Howieson DB, Bigler ED, Tranel DD. *Neuropsychological Assessment*. New York: Oxford University Press, USA; 2004.
22. Corrigan JD, Hinkeldey NS. Relationships between parts A and B of the Trail Making Test. *J Clin Psychol* 1987 Jul;43(4):402-409. [Medline: [3611374](https://pubmed.ncbi.nlm.nih.gov/3611374/)]
23. Jorgensen MG, Laessoe U, Hendriksen C, Nielsen OB, Aagaard P. Efficacy of Nintendo Wii training on mechanical leg muscle function and postural balance in community-dwelling older adults: a randomized controlled trial. *J Gerontol A Biol Sci Med Sci* 2013 Jul;68(7):845-852. [doi: [10.1093/gerona/gls222](https://doi.org/10.1093/gerona/gls222)] [Medline: [23114461](https://pubmed.ncbi.nlm.nih.gov/23114461/)]
24. Sullivan B, Harding AG, Dingley J, Gras LZ. Improvements in dynamic balance using an adaptive snowboard with the Nintendo Wii. *Games for Health Journal* 2012 Aug;1(4):269-273. [doi: [10.1089/g4h.2012.0006](https://doi.org/10.1089/g4h.2012.0006)]
25. Schoene D, Lord SR, Delbaere K, Severino C, Davies TA, Smith ST. A randomized controlled pilot study of home-based step training in older people using videogame technology. *PLoS One* 2013;8(3):e57734 [FREE Full text] [doi: [10.1371/journal.pone.0057734](https://doi.org/10.1371/journal.pone.0057734)] [Medline: [23472104](https://pubmed.ncbi.nlm.nih.gov/23472104/)]

Abbreviations

CG: control group
DT: dual task
DTTC: Dual-Task Tai Chi
TG: training group
TMT: trail-making test
VFT: verbal fluency test

Edited by H Fardoun; submitted 19.11.13; peer-reviewed by V Penichet, G Wolbring; comments to author 09.12.13; revised version received 15.01.14; accepted 22.01.14; published 24.02.14

Please cite as:

Kayama H, Okamoto K, Nishiguchi S, Yamada M, Kuroda T, Aoyama T
 Effect of a Kinect-Based Exercise Game on Improving Executive Cognitive Performance in Community-Dwelling Elderly: Case Control Study
J Med Internet Res 2014;16(2):e61
 URL: <http://www.jmir.org/2014/2/e61/>
 doi:[10.2196/jmir.3108](https://doi.org/10.2196/jmir.3108)
 PMID:

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