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Effects of Exercise Program Requiring Attention, Memory and Imitation on Cognitive Function in Elderly Persons: A Non-Randomized Pilot Study

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Abstract

Background: Square-Stepping Exercise (SSE) was developed as a novel exercise form that combines physical and cognitive training. Participants watch, recognize, memorize and follow step patterns which an instructor demonstrates on a 4 by 10 square-patterned SSE mat without viewing printed pattern diagrams. The purpose of this study was to examine the effects of SSE on cognitive function.

Methods: Community-dwelling, healthy elderly persons were non-randomly divided into a weekly session group (WG) (26 participants) and a fortnightly session group (FG) (32 participants) for a six month intervention. SSE sessions lasted 50-60 minutes, and an SSE mat was provided to participants for home use. We asked participants to review printed pattern diagrams at home, then practice the SSE and record this in a log. Five cognitive tests were given pre- and post-intervention: cued recall, character position referencing, animal name listing, clock drawing and an analogy test.

Results: Both groups significantly improved in the cued recall test (memory): 2.7 points [95% confidence interval (CI): 1.1-4.4] in the WG and 2.4 points [95%CI: 0.9-4.0] in the FG. Furthermore, the WG significantly improved in the character position referencing test (executive function) (5.6 points [95%CI: 2.8-8.3]). The three other cognitive function tests did not significantly improve. On the cued recall test, the rate of session participation and the rate of SSE performance for all designated days positively correlated in the WG/FG combined data. On the character position referencing test, the total SSE time and the number of days SSE was performed at home and in session were significant in the WG/FG combined data.

Conclusion: The results of this pilot study indicate that SSE be could use as an intervention to promote cognitive function, especially memory and executive function. The amount and/or frequency of exposure to SSE would affect its impact on various types of cognitive function.

Keywords: Training; Fitness; Square-stepping exercise; Cognitive impairment; Memory; Executive function

Introduction

Worldwide, nearly 35.6 million people live with dementia. This number is expected to nearly double to 65.7 million by 2030 and more than triple to 115.4 million by 2050 [1]. Dementia affects people in all countries, with more than half (58%) living in low- and middle-income countries [1]. It is estimated that delaying dementia onset by 2 years could decrease global disease burden in 2050 by 22.8 million cases [2]. This underscores the urgency of maintaining cognitive function and decreasing dementia.

Identifying risk factors associated with cognitive decline, especially early in the process, is critical for formulating prevention or intervention strategies. Various pastimes, including intellectual activities, are associated with a lower risk for dementia such as recollecting, gardening, singing and playing board games [3]. Physical exercise also lowers the risk for dementia [4,5]; it has a reciprocal relationship with cognitive performance because increased exercise leads to better cognitive function and brighter people exercise more [6]. Erickson et al. [7] showed that one year of walking can increase the size of the hippocampus and improve cognitive function in elderly persons. A study by Verghese et al. [3] showed that those who dance frequently had a lower hazard ratio for dementia compared to those who rarely danced. These studies suggest that either intellectual activity or exercise can delay or prevent a decrease in cognitive function. Combining intellectual activities with exercise may, therefore, produce assured and significant effects.

We have developed a novel exercise named "Square-Stepping Exercise (SSE)" [8], details of which are described in Methods. In brief, SSE is a physical exercise which also requires cognitive function by including intellectual activities such as attentiveness, memory and imitation. Other researchers regard this exercise as dual-task training [9]. We have confirmed that SSE improves risk factors for falling [10], and leading falling risk [11]. However, effects of SSE on cognitive function have not been well established. Since SSE requires memorizing various step patterns, from very easy to very difficult, this exercise could be another way of improving cognitive function. The purpose of this study was to determine the effects of SSE on cognitive function in elderly persons. Furthermore, we tried to determine how the amount and frequency of SSE related to the effects we observed.

Methods

Study design and participants

This study was a non-randomized controlled study. Because the

present study was a pilot study to inform a larger study, we did not conduct a priori sample size calculation. The main outcome measures were cognitive functions. Participants were recruited from the area superintended by one of nine community general support districts managed by Tsu city (711 km², 24.1% of residents aged 65 years or older), Mie Prefecture, Japan. An informational letter about the intervention and scheduling was sent to all households with elderly persons who had senior citizens club's co-sponsorship in the area (approximately 9,200 households). Two centers in the area participated as intervention sites. People interested in participating in the study could attend the more accessible center (non-randomized allocation). We excluded persons diagnosed with dementia, those having severe neurological or cardiovascular disease and those with mobility-limiting orthopedic conditions. To determine the effects that cumulative exposure vs. frequency of exposure to SSE may have, we set up a different schedule at each center. One site had SSE sessions every week (Weekly Group:WG) and the other site operated every 2 weeks (Fortnightly Group:FG). We held 22 and 13 sessions for the WG and FG, respectively, during the six month intervention period, with sessions lasting 90 minutes, and the actual SSE lasting 50-60 minutes.

This study was approved by the ethical committee of Mie University Graduate School of Medicine (No. 1194). All participants gave their written informed consent to participate in this study.

Measurements

Cognitive function: To measure cognitive function of the participants, we used a 5-test battery named Five Cog Test [12]. The test battery requires 45 minutes to complete using a projector, screen, DVD and paper answer sheets. The battery was developed by the International Psychogeriatric Association to screen persons with age-associated cognitive decline (AACD) [13]. It is composed of five tests: cued recall test, character position referencing test, animal name listing test, clock drawing test and analogy test. The test battery has been validated by the Logical memory I and II subtests of the Japanese version of the Wechsler Memory Scale-Revised [14], the Trail Making Test [15] and an analogy of the Japanese version of the Wechsler Adult Intelligence Scale-Revised [16]. It is confirmed as highly reliable [12].

Test methodology:

Cued recall test (memory test): Participants watched a screen in front of them displaying four nouns at a time such as golf, violet, physician and lemon and listened while each word was spoken. The participants were asked to speak the word after each verbal introduction. Eight consecutive screens were displayed for two minutes each for a total of 32 words on the eight screens over 16 minutes. The 32 words were derived from eight categories: sports, flowers, occupations, fruits, trees, fish, countries and kitchen equipment. After all words were introduced, the participants took other cognitive tests for 10 minutes before they were asked to write down all 32 words in four minutes on an answer sheet next to the eight category names listed along the side. The number of correct words was the test score (score range: 0 to 32).

Character position referencing test (executive function test): On an answer sheet, 80 Chinese characters were situated on one of three vertical levels running from left to right on a paper. One third of all characters were located at the center baseline level while the other characters were located 13 millimeters above or below the baseline. There were only three characters, "Ue" (which means "above"), "Naka" ("middle or baseline"), and "Shita" ("below"), and their locations on any of the three levels were random. Solid lines connected adjacent letters (diagonally up and down or side to side, although horizontal lines indicating each level did not appear across the sheet). Participants were asked to circle the character only if its meaning corresponded to the level at which it was located. For example, the character "Ue" (which means "above") should be circled when it was located above the baseline. Nothing was done to a character which did not correctly match its level. Furthermore, they were asked to simultaneously and sequentially number each circle indicating how many circles were on the sheet. The test was one minute long, and the number of correct circles was the test score (score range: 0 to 40).

Animal name listing test (Word fluency test): Participants were asked to list as many animal names as possible in two minutes (score range:0 to 40).
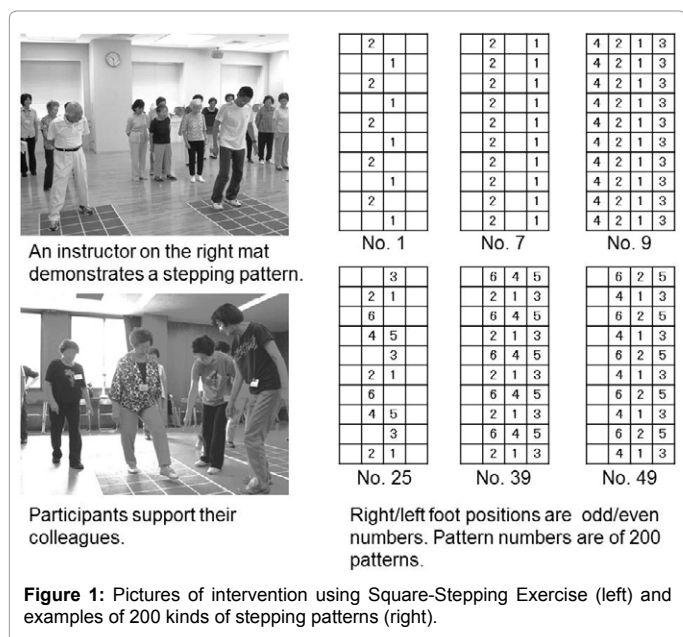
Clock drawing test (visuospatial test): This test was similar to one used by Libon et al. [17]. Before the test, we removed the wall clock from the room and asked participants to remove their watches. The participants were asked to draw an analog clock indicating "ten after eleven" (11:10) on white paper in 90 seconds. There were seven assessment points for the test score (score range: 0 to 7).

Analogy test (Similarity test): Participants were shown 16 pairs of words on a sheet of paper and asked to write one word that described the two items, for example, "gem" or "jewel" would describe the words "ruby and diamond." Three minutes were allowed to perform the test (score range: 0 to 16).

Sociodemographic information and other characteristics: Prior to the intervention, we measured the participant's body weight and height by usual methods. We used individual interviews to perform a Mini-Mental State Examination [18] on each participant. We used a questionnaire to evaluate participants' ability to perform 29 types of instrumental activities of daily living (IADL), years of education, smoking status and presence of diabetes mellitus, which might affect cognitive function [19]. Post-intervention, we assessed participants' experience with 18 life events that may have occurred during the intervention, such as retirement and bereavement, which could affect cognitive function [20,21].

Square-Stepping Exercise (SSE) and intervention: In the SSE session, a thin mat (100 cm by 250 cm) which was partitioned into 40 squares (25 cm on a side) was used. An SSE instructor demonstrated a stepping pattern to participants without verbal instructions about the pattern; the instructor proceeded from one end of the mat to the other one by stepping her/his feet on certain squares. Before starting, the instructor asked all participants in each group to observe which squares the instructor stepped on to be able to recognize the pattern and remember it (Figure 1). They were then asked to step on the mat in the pattern that the instructor had just demonstrated. There are 200 available stepping patterns which allow instructors to choose an appropriate pattern for participants. Once participants complete a pattern, the instructor proceeds to more difficult patterns for participants to imitate. The process requires mental activity such as recall, executive function, visuospatial function and analogy.

Although participants did not receive written instructions or diagrams of the patterns they would be performing during the session, we allowed the participants to observe the patterns as many times as desired to memorize them. Participants could also teach the patterns to each other through verbal instruction and body language, which also required cognitive functions such as recall, visuospatial function and word fluency. Pattern recognition and memorization could usually be achieved after 4-5 repetitions. When they completed a pattern, the instructor showed them another pattern. During a session, the

Figure 1: Pictures of intervention using Square-Stepping Exercise (left) and examples of 200 kinds of stepping patterns (right).

instructor demonstrated 6-8 patterns which the participants would practice again in the next session before learning new patterns.

We provided a SSE mat to each participant for home use. They were to repeat at home those patterns they felt were difficult every day as homework. Although we provided diagrams showing the patterns they had learned in the most recent session, we asked participants to look at them prior to but not during the homework because we wanted them to memorize and recall the patterns. Participants were to perform their homework for at least 10 minutes daily for one week following each session. Therefore, WG participants performed SSE every day between sessions, whereas, FG participants had one week of SSE homework and one week without SSE homework between sessions. The amount and frequency of the FG's exposure to SSE was half that of the WG's exposure. Participants recorded their homework and sessions in a daily log from which we calculated (1) rate of session participation, (2) total time spent on SSE during the six month intervention, (3) number of days they performed SSE at home and in session, (4) rate of SSE performance for all designated days, and (5) minutes per day spent on SSE. Participants did not receive anything valuable as rewards but were verbally motivated to attend the sessions and to do homework.

Statistical analysis: After confirming normal distributions in each measurement, we calculated means and standard deviations (SD) or proportions for multiple sociodemographic groupings and other information on the participants. We applied unpaired t-test and chi-square analysis to detect significant differences between 2 groups and calculated unadjusted means and 95% confidence intervals (95%CI) for each cognition measure that changed between the baseline and follow-up measurements. We also calculated adjusted means and 95%CI controlling for sex, age, education, the number of difficulties performing IADL and Mini-Mental State Examination score at baseline, and the number of life events that occurred during the intervention (our covariates) [5,12,19,22]. To explore which variables of the SSE protocols relate to changes in cognitive function, Pearson's correlation coefficients were calculated. Partial correlation coefficients, adjusting for the above covariates were also calculated.

Use-effectiveness, which is the gross (public) effect of SSE on those

who registered in the study, was analyzed based on the intention-to-treat (ITT) principle. For the analysis, we included data from the baseline measurement when participants did not participate in the follow-up measurement. IBM SPSS Statistics (Ver. 21) was used in all analyses. Statistical significance was set at < 5%. Any information and data on each group were not blinded to authors.

Results

At the baseline measurement, there were 26 people in the WG and 32 persons in the FG. There were no significant differences in sociodemographic information or cognitive function (Table 1 and Figure 2). During the intervention period, four WG participants and three FG participants dropped out of the study due to personal reasons and time constraints (Table 2). For the remaining participants, session participation rates were 89% ± 11% (20 of 22 sessions) in the WG and 84% ± 17% (11 of 13 sessions) in the FG. No adverse events such as falling were experienced by the participation during the study period. Between the two groups, participants learned the 156th stepping pattern out of 200 available patterns. On average, those in the WG reviewed 4.9 ± 4.1 patterns and tried 7.2 ± 2.6 new patterns in one session (12.1 ± 3.5 patterns in total). Those in the FG reviewed or newly learned 5.0 ± 4.0 and 7.0 ± 2.8 patterns, respectively (12.0 ± 3.3 patterns in total). Due to the difference in session frequency, the number of SSE patterns learned and the total time of exposure to SSE in the WG was double that of the FG over six months (Table 2). A similar difference was found in the number of days SSE was performed at home and in session.

At the follow-up measurement, we found a significant change in the cued recall test in each group. The change in the character position referencing test in the WG was also significant, and it was significantly higher than that in the FG. No significant changes were found in the other three tests (Table 3).

We calculated Pearson's and partial correlation coefficients on variables in the SSE protocols and the two cognitive functions that improved significantly (Table 4). On the cued recall test, the session participation rate and the rate of SSE performance for all designated

Variable	Weekly Group n = 26	Fortnightly Group n = 32
Demographic information		
Female [female ratio] (n [%])	21 [81%]	30 [94%]
Age (yr)	75.9 ± 5.0	73.1 ± 5.3
Height (cm)	150.7 ± 9.0	151.8 ± 5.4
Weight (kg)	54.0 ± 6.7	52.4 ± 8.1
Body mass index (kg/m²)	23.9 ± 3.2	22.6 ± 3.0
Education (yr)	11.4 ± 2.5	11.4 ± 2.2
Number of difficulties in IADL (n) [a]	1.8 ± 1.6	1.7 ± 1.6
Current smoking [ratio] (n [%])	0 [0%]	0 [0%]
Diabetes mellitus [ratio] (n [%])	1 [4%]	3 [9%]
Cognitive function		
Mini-Mental State Examination	26.1 ± 2.4	26.5 ± 1.8
Five-Cog test		
1) Cued recall test	12.7 ± 5.6	14.0 ± 4.7
2) Character position referencing test	13.8 ± 9.8	14.0 ± 8.7
3) Animal name listing test	14.1 ± 4.8	15.0 ± 4.1
4) Clock drawing test	6.7 ± 0.5	6.8 ± 0.5
5) Analogy test	10.0 ± 3.3	10.6 ± 2.9

Values are expressed as means ± standard deviations except for percentage
[a]IADL = instrumental activities of daily living
No significant differences between groups in each variable

Table 1: Characteristics of study participants at baseline

Figure 2: Consolidated standards of reporting trial diagram.
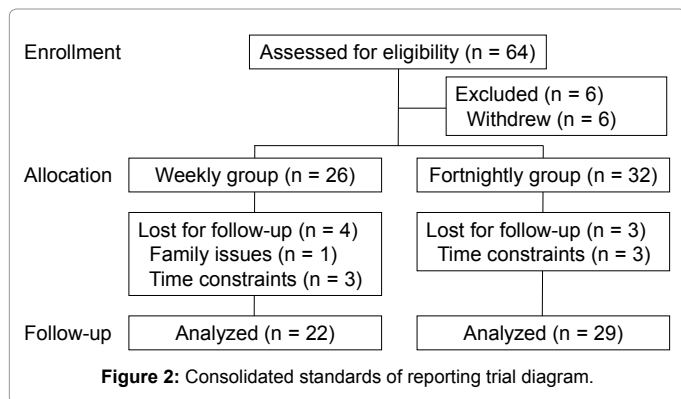
Variable	Weekly Group	Fortnightly Group
Rate of session participation (%)	89 ± 11	84 ± 17
Number of life events (n) [b]	1.27 ± 2.21	1.75 ± 2.00
Total SSE time (min / 6 mo)	1294 ± 155	618 ± 126*
Days SSE performed at home and in sessions (days)	136.9 ± 33.7	58.0 ± 19.8*
Rate of SSE performance for all designated days (%)	76 ± 19	64 ± 22
Daily time spent on SSE (min / designated day)	10.3 ± 4.1	14.5 ± 16.7

Values are expressed as means ± standard deviations except for percentage.
SSE = Square-Stepping Exercise
[a] Each variable does not include participants who dropped out
[b] Life events were counted if they happened during the intervention.
*A significant difference between the groups.

Table 2: Variables during the intervention in each group[a].

Variable		Weekly Group	Fortnightly Group	
Cued recall test	Crude	2.5 (3.7) [1.0–3.9]*	2.4 (3.4) [1.1–3.7]*	
	Adjusted	2.7 [1.1–4.4]*	2.4 [0.9–4.0]*	
Character position referencing test	Crude	5.1 (6.5) [2.6–7.6]*	1.6 (5.2) [-0.9–4.1]	†
	Adjusted	5.6 [2.8–8.3]*	1.3 [-1.7–4.3]	†
Animal name listing test	Crude	1.2 (4.0) [-0.5–2.9]	0.6 (4.0) [-0.8–2.1]	
	Adjusted	1.1 [-0.7–3.0]	0.8 [-0.9–2.5]	
Clock drawing test	Crude	-0.1 (0.8) [-0.4–0.1]	0.1 (0.4) [-0.1–0.4]	
	Adjusted	-0.1 [-0.4–0.2]	0.1 [-0.2–0.4]	
Analogy test	Crude	0.6 (3.2) [-0.5–1.7]	0.0 (2.2) [-1.0–1.0]	
	Adjusted	0.5 [-0.7–1.8]	0.1 [-1.1–1.2]	

Values present as mean (standard deviations) [95% confidence interval].
Adjusted values = adjusted for covariates (age, sex, education, number of difficulties in IADL and Mini-Mental State Examination score at baseline, and number of life events during the intervention).
*Significant difference between pre- and post-intervention within group.
† Significant difference between groups.

Table 3: Pre- and post-intervention changes in cognitive function in each group.

days were positively correlated in the WG/FG combined group data. The number of SSE homework days and sessions in the WG and the total time spent on SSE in the FG also correlated significantly with the cognitive improvements. On the character position referencing test, total SSE time and the number of SSE homework days and sessions were significant in the WG/FG combined group data. No significant differences in correlation coefficients between the groups were found in any variables.

Discussion

Exercise leads to enhanced neuronal health and function, which could minimize the clinical impact of neuronal loss that may occur early in the dementia process [5]. Therefore, an important goal for researchers should be identifying the most effective exercises for neuronal health and function. To this end, we examined Square-Stepping Exercise (SSE) for elderly persons. In this study, those who participated in the SSE sessions either weekly or fortnightly improved in the cued recall test. Furthermore, those in the WG also significantly improved in the character position referencing test, although those in the FG did not.

There have been several reports on the effects of exercise on cognitive function in the past decade. Although the mechanism for the relationship between exercise and cognitive functioning is not well understood, several researchers have suggested that enhanced blood flow, increased brain volume, elevations in brain-derived neurotropic factor and improvements in neurotransmitter systems and IGF-1 function may occur in response to exercise [23]. Other activities such as cognitive training also improve cognitive function; those who took "brain training" using a personal computer significantly improved their memory function [24,25]. Reading aloud and doing math also improve frontal functions in dementia [26]. Looking at these previous studies, we see there are two major interventions that can improve cognitive function, namely exercise and cognitive training.

Square-Stepping Exercise (SSE) utilizes both exercise and cognitive training [9] because persons must watch and memorize SSE patterns and then move/step as instructed. It would, therefore, be worthwhile to examine the effects of SSE on cognitive function in elderly persons. We reported previously on the effects of SSE [27]. However, the control group in that study received health education only; there was no exercise or cognitive training. In this study, we also had the control group participate in the SSE.

Through the 6-month SSE intervention, the cued recall test improved significantly. Memorization of SSE patterns was repeated in each session and at home. Although we took a time of 6 months between the pre- and post-intervention measurements that was recommended in a previous study [12], a learning effect (bias) might be existed. Our results, however, suggest that memorization for cognitive training and stepping for exercise led to the improvements. This assumption is supported by previous studies on exercise [28] and cognitive training [24].

SSE also improved the mean score for the character position referencing test, which could be considered a measure of executive function [29], in the WG. Executive functions are the high-level cognitive processes that facilitate new ways of behaving and optimize one's approach to unfamiliar circumstances [30]. There is compelling evidence from animal studies that exercise may directly enhance neuronal health and function [31]. From human studies, aerobic exercise has been confirmed as a means to improve executive function [28]. In this study, watching, memorizing and stepping in many patterns required this function. Results from these previous studies are comparable to our results.

One unique point of SSE that may contribute to improved cognitive function is the increased social interaction that SSE provides participants. Although the instructor initially demonstrates a pattern while participants quietly observe and then attempt to step the pattern themselves, some participants cannot repeat it. This provides everyone the opportunity to teach the pattern to each other which encourages communication, praise, fun, laughter and understanding among them. Decreased social activity is considered a risk factor for dementia [31,32],

Variable	Pearson's coefficient			Partial coefficient		
	All	Weekly Group	Fortnightly Group	All	Weekly Group	Fortnightly Group
Cued recall test						
Rate of session participation (%)	0.23*	0.27	0.39*	0.35*	0.31	0.60*
Total SSE time (min / 6 mo)	0.03	0.27	0.41*	0.12	0.31	0.60*
Days SSE performed at home and in session (days)	0.22	0.52*	0.19	0.19	0.49*	0.02
Rate of SSE performance for all designated days (%)	0.32*	0.53*	0.19	0.32*	0.49*	0.02
Daily SSE time (min/ designated day)	-0.17	-0.20	-0.14	0.21	0.11	0.31
Character position referencing test						
Rate of session participation (%)	0.01	0.18	-0.23	-0.05	0.04	-0.15
Total SSE time (min / 6 mo)	0.24*	0.20	-0.23	0.31	0.07	0.08
Days SSE performed at home and in session (days)	0.29*	0.23	-0.24	0.31	0.28	0.33
Rate of SSE performance for all designated days (%)	0.10	0.24	-0.24	0.03	0.28	-0.22
Daily SSE time (min / designated day)	-0.11	-0.23	-0.03	-0.05	-0.32	0.33

SSE = Square-Stepping Exercise.
Partial correlation coefficients were adjusted for covariates (age, sex, education, the number of difficulties in IADL and Mini-Mental State Examination score at baseline, and the number of life events during the intervention).
*A significant coefficient.
No significant differences between coefficients in each variable.

Table 4: Pearson's and partial correlation coefficients between changes in cued recall test, character position referencing test and SSE protocols.

so environmentally-enriched conditions that include social interaction can enhance learning [33]. The social interaction that occurs through SSE might, therefore, contribute to improved cognitive function. This speculation is also supported by the significant correlation between cognitive function improvement and rate of session participation (Table 4), i.e., the more frequently participants attended sessions, the more the recall test score improved.

As shown in Table 4, the improvement in the cued recall test score correlated positively with the session participation rate and the total SSE time in the FG and in the WG/FG combined data. This suggests that there is a dose-response relationship between the variables. During the six month intervention, those in the FG attended 10 sessions on average for approximately 600 minutes of total SSE time. This amount of exposure to SSE may be a rough standard for significantly improving the recall function. In the WG, the total SSE time did not correlate significantly to improved cued recall, but the number of days SSE was performed at home and in session, and the rate of SSE performance for all designated days did correlate. From these results, it seems that once SSE practice time reaches about 600 minutes over six months, individuals should focus on how often they perform SSE and not simply the amount of time practicing. Unlike our results with the cued recall test, total SSE time and the number of days SSE was performed at home and in session in the WG/FG combined data correlated significantly with the change in the character referencing position test. Daily SSE time was not significantly correlated with the item. From those results it seems that increasing the amount but not the frequency of SSE might improve executive function.

Three other cognitive tests did not improve significantly in this study. In the clock drawing test, the initial test score was close to perfect (approximately 6.8/7 points or 96%). SSE does require visuospatial integration by gazing at the instructor's feet and squares to determine the pattern, so if a more complicated visuospatial test is applied, the test score might improve significantly. Similar reasoning could be applied to the paired words analogy test. The average score (10 points) was equivalent to 63% of the perfect score. The animal name listing test also did not improve, likely due to the nature of the SSE intervention; other

types of cognitive training such as gaining knowledge in a subject area may be necessary to improve that function.

There are some limitations in the study. First, the participants were not randomly allocated into their groups, which does not guarantee homogeneity of the two groups. Also, the small sample size limits generalizability and precision of data interpretation. Second, we did not collect the data on other cognitive activities other than SSE that the participants may have been performing. These other activities might have affected the results. Third, the participants may have over- or underestimated their log entries which would affect the correlation analyses.

In conclusion, we do not claim that SSE should be a substitute for other exercises, but propose it as a complementary exercise, which would be particularly suitable for those who want to improve memory and executive function. Because SSE is also a low-cost and low-tech exercise, it could be used in low- and middle-income countries where more than half of those with dementia live.

Acknowledgement

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