AJPESH 2 (2) (2022): 70-77 e-ISSN 2548 - 7604
ACPES Journal of Physical Education, Sport, and Health http://journal.unnes.ac.id/sju/index.php/ajpesh

Short-Term Effects of Square Stepping Exercise on Cognitive and Social Functions in Sedentary Older Adults: A Home-Based Online Trial

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Submitted: 2022-08-18. Accepted: 2022-10-29. Published: 2022-12-02

Abstract. The Square Stepping Exercise (SSE) is an exercise training program integrating physical exercise and cognitive components. The potential of SSE in deferring cognitive decline in older adults is encouraging. However, the coronavirus pandemic has made it harder for older adults worldwide to exercise together in person. Therefore, the present study aimed to investigate the short-term effects of a home-based online SSE trial on cognitive and social functions in sedentary older adults. Methods of this research use sample of 24 older adults (2 men, 22 women) took part in the current study. Seven participants (2 men, 5 women) completed home-based online SSE sessions under tighter safety regulations, whereas other 17 women attended SSE sessions in person when group exercise with more than 5 people were permitted. To investigate the effects of the online SSE on cognitive and social functions compared to the in-person SSE, 2 times (pre vs. post) × 2 groups (online vs. in-person) mixed ANOVAs were conducted with classic and robust statistical methods on the scores of the Trail Making Test (TMT), the subscale scores of the Physical Activity Group Environment Questionnaire, and the score of the Subjective Vitality Scale. Results: The interaction between time and groups was significant on the TMT-B to TMT-A (B/A) ratio score (p = .049) and the subscale scores of Individuals Attractions to the Group–Task (p = .034) and –Social (p = .037). The B/A ratio score is an indicator of executive control function. The online SSE group's ratio score slightly decreased over the sessions, whereas the ratio scores significantly increased in the in-person group. As for group cohesion, participants' involvements with the group task and social interaction with their group were enhanced in the online SSE group over the sessions, compared to the in-person SSE group. Conclusions: In this study, SSE was carried out online for a short-term and found to be successful to enhance executive function and group cohesion in sedentary older adults. Considering the coronavirus pandemic circumstances, it is valuable to examine the long-term effects of the online SSE in older adults in future research.

Key words: COVID-19, Executive control function, Group cohesion, Integrated exercise, Online intervention

How to Cite: Gan, S. R., Low, K., Okura, T., Kawabata, M. (2022). Short-Term Effects of Square Stepping Exercise on Cognitive and Social Functions in Sedentary Older Adults: A Home-Based Online Trial. *AJPESH* 2 (2) (2022): 70-77.

INTRODUCTION

Cognitive and physical exercise conducted independently is useful to improve cognition in both cognitively normal and cognitively harmed people. Through a review of relevant intervention studies, Karr et al. (2014) have proposed that integrating both exercise and cognitive training in an intervention program may be more helpful to promote the improvement. However, this type of training has yet to be well examined and conducted.

A training program that includes both physical exercise and cognitive elements is the Square Stepping Exercise (SSE: Shigematsu & Okura, 2006). SSE is a type of stepping exercise training that can be easily done in a group environment. It was created for older adults to do exercise indoor by overcoming difficulties faced when walking outdoors. Moreover, SSE has the possibility to support social interactions when it is done in a group environment (Shigematsu & Okura, 2006).

Early research of 12-weeks SSE program conducted in Japan showed that SSE was efficient to diminish fall risks in healthy community dwelling older adults (Shigematsu & Okura, 2006; Shigematsu

et al., 2008a, 2008b). Ravichandran et al. (2017) stated that a 4-week SSE program was effective to increase gait abilities and balancing of older adults with Parkinson's disease. These findings are supported by meta-analytic reviews of the effectiveness of SSE on fall prevention (Fisseha et al., 2017; Nokham, & Kitisri, 2014). It was indicated that SSE is efficient in inhibiting the dangers of falling by enhancing balance. The SSE was also found to improve older adults' depressive signs (Pereira et al., 2017) and cognitive functions (Teixeria et al., 2013; Shigematsu et al., 2014; Noma et al., 2020). Teixeria et al. (2013) also found that a 14-week SSE program was efficient to enhance attention, global cognition, and mental flexibility in Brazilian older adults. Furthermore, cognitive gains in executive function and memory were observed in Japanese older adults (Shigematsu et al., 2014; Noma et al., 2020).

Acute versus chronic exercise is one of crucial distinctions regarding the protocols to examine the effect of exercise on physical and cognition functions and they need to be differentiated (Audiffren, 2009). However, there is scant research on the acute effects of SSE on cognitive functions. To address the research gap, Kawabata et al. (2021) recently examined the acute effects of SSE on cognitive and social functions in sedentary young adults. People across the world have been forced to alter their lifestyle and behaviors since the outbreak of coronavirus (COVID-19) disease. When participating in a group exercise, individuals have been required to maintain a sufficient space from others and diminish physical contacts to avoid infection. Therefore, Kawabata et al. (2021) invented protocols to conduct a home-based SSE trial online to increase the safety of participants and reported that the online SSE was efficient to improve executive function and group cohesion in sedentary young adults.

The potential of SSE in deferring cognitive decline in older adults is encouraging (Teixeria et al., 2013; Shigematsu et al., 2014; Noma et al., 2020). However, the coronavirus pandemic has made it harder for older adults worldwide to exercise together in person. Individuals aged 60 years and above are more vulnerable to the coronavirus and at higher risk of leading to serious conditions. Considering the coronavirus pandemic circumstances, it is valuable to consider the option of conducting SSE online for older adults and examine the effectiveness of this approach. Therefore, the purpose of the present study was to investigate the short-term effects of a home-based online SSE trial on cognitive and social functions in sedentary older adults.

METHODS

Participants and Procedures

A sample of 24 older adults (2 men, 22 women; M_{age} = 66.5 years, *SD* = 5.1; $M_{body\ mass\ index}$ = 24.29 kg/m2, *SD* = 3.62) took part in the current study. Seven participants (2 men, 5 women) completed home-based online SSE sessions under tighter safety regulations, whereas 17 women attended SSE sessions in person, when group exercise with more than 5 people were permitted. No overlap in participants between online and in-person SSE. Participants' characteristics are summarized for each group in Table 1. Based on Kawabata et al.'s (2021) study, participants were recruited in Singapore with the subsequent inclusion criteria: (a) no psychiatric or neurological illnesses, (b) aged between 55 and 80 years old; and (c) exercise less than three times per week and not more than 30 minutes each time.

Ethical approval was acquired from an Institutional Review Board at Nanyang Technological University (NTU), Singapore (Ref: IRB-2020-04-014). Participation was voluntary and informed consent was obtained from every participant before any data collections. This study was carried out consistent with the approved guidelines and procedures involving human subjects, which were approved by the Institutional Review Board.

Table 1. Characteristics of Participants

	Total (N = 24)	**Online (n = 7)**	**In-Person (n = 17)**
		Male (n = 2) Female (n = 5)	Female (n = 17)
Age (years)	66.54 (±5.13)	64.14 (±7.27)	67.53 (±3.81)
BMI (kg/m2)	24.29 (±3.62)	23.52 (±3.19)	24.61 (±3.84)
Attendance rate (%)	—	97.62 (±6.30)	68.71 (±4.65)

Note. Data are *Mean* (*SD*). BMI = body mass index.

Exercise Protocol

Square Stepping Exercise. SSE was conducted on a thin mat (100 cm × 250 cm) that was partitioned into 40 squares (25 cm each). The SSE program consisted multi-direction movements, involving forward, backward, lateral and oblique step patterns. They are classified into 3 levels (elementary, intermediate, and advanced) based on the difficulty of the stepping patterns (Shigematsu & Okura, 2006; Shigematsu et al., 2008b, Kawabata et al., 2021).

SSE step patterns were introduced to participants by following standard procedures (Shigematsu & Okura, 2006; Shigematsu et al., 2008b, Kawabata et al., 2021). At the start of each round, an instructor demonstrated a stepping pattern to participants. They were asked to remember the pattern shown. Then, they stepped from one end of the mat to the other by following the stepping pattern. Participants had to carry out each pattern correctly two to three times before continuing to a more difficult step pattern. They took turns to execute the pattern presented in each round. Once finished, participants returned to the initial position by walking outside the mat.

Each exercise session comprised of 10 minutes of warm-up activities, 40 minutes of SSE, and 10 minutes of cool-down. In each SSE session, three stepping patterns were instructed on average.

Online SSE sessions. SSE was implemented online by following Kawabata et al.'s (2021) study. The exercise sessions were conducted at participant's home online through Zoom, an online video meeting software, and were scheduled in the morning from late September to middle October 2021. All the sessions were led by an instructor who was trained by a certified SSE trainer. Participants consisted of three pairs (e.g., couples, sisters, or friends) and single individual since the maximum group size was limited to two under tighter safety regulations at that time. (Originally, there were four pairs, but a participant dropped out due to a personal reason.) Participants were asked to join two sessions per week over three weeks. They attended most sessions (97.6%) although one participant missed a session only.

Each pair of participants obtained one SSE mat from the researcher before the first SSE session. They were instructed to set the device with a video camera at a suitable position so that the instructor can see the whole mat and assess participant's performance obviously. To simulate the social conditions of an in-person SSE session, communications between participants were also encouraged in the online SSE session based on Kawabata et al.'s (2021) study. Partners in each pair were asked to provide reinforcements through doing high-fives virtually and making encouraging comments whenever their partners have finished their turn of the SSE exercise.

All participants were asked to pass the evaluation round in order for the entire group to progress through the patterns. The criteria for passing each evaluation were consistent with Kawabata et al.'s (2021) study.

In-person SSE sessions. The exercise sessions were conducted in person at a sport center in the morning from late March to early June 2021. Sessions were led by an instructor who is a certified SSE trainer. However, the instructor was changed several times due to the lack of manpower at the sport center. In every session, participants were divided to three or four groups of five individuals since the maximum group size was limited to five under safety regulations at that time. Participants were asked to join two sessions per week over seven weeks. Their attendance rate ranged from 33.3% to 76.2% with an average rate of 68.7%. Participants in each group were asked to provide reinforcements through doing non-touching high-fives and making encouraging comments whenever their group members have finished their turn of the SSE exercise.

Measures

Executive function. The Trail Making Test (TMT) was carried out by using Savonix (2021) to measure speed of cognitive processing and executive function such as cognitive flexibility (Sánchez-Cubillo et al., 2009). The test is comprised of two parts (A and B). Part A (TMT-A) is related to motor control and perceptual abilities and Part B (TMT-B) is considered to reflect working memory and task-switching ability (Arbuthnott & Frank, 2000; Sánchez-Cubillo et al., 2009). The time to complete the tasks is used as the direct score of each part, and two derived scores (the B-A difference and the B/A ratio) are often used in clinical practice as an indicator of executive control function, which is independent of motor speed and visual scanning speed (Arbuthnott & Frank, 2000; Sánchez-Cubillo et al., 2009). The TMT was completed by participants in both groups before the first SSE session and after the last SSE session.

Group cohesion. The Physical Activity Group Environment Questionnaire (PAGEQ: Estabrooks & Carron, 2000) was employed to assess participant's thoughts of cohesion in their physical activity groups. The PAGEQ is an instrument with 21 items, consisting of the four subscales: Individual Attractions to the Group-Task (ATG-T: personal participation in the group task), Individuals Attractions to the Group-Social (ATG-S: personal approval and social communication with the group), Group Integration-Task (GI-T: the bonding and closeness that exists within the group as a whole around its joint task), and Group Integration-Social (GI-S: the bonding and closeness that exists within the group as a whole around social matters). Participants were requested to show the degree to which they agreed with the statement of each item by using a 9-point Likert-type scale, which ranged from 1 (*very strongly disagree*) to 9 (*very strongly agree*). In both groups, participants filled out the PAGEQ before the first SSE session and after the last SSE session.

Subjective vitality. The Subjective Vitality Scale (SVS: Ryan, & Frederick, 1997) is a self-report instrument that is designed to evaluate feelings of energy and vitality. There are state and trait versions. Based on Kawabata et al. (2017), the five-item trait-version of the SVS was employed in the current study. Participants were requested to show the degree to which the statement of each item was true for them "in general in their life" based on a 7-point Likert-type scale, which ranged from 1 (*not at all true*) to 7 (*very true*).

Physical tests. A walk and a single-leg balance test were used to measure participant's physical functioning abilities. The physical tests were completed by participants in the in-person groups before the first SSE session and after the last SSE session. Physical tests were not conducted for the online group due to tighter safety regulations against coronavirus pandemic. For the gait test, participants had to walk along a straight 11-meter walkway at their (1) usual pace once, and (2) maximum pace twice (the faster measurement was taken; Taniguchi et al., 2017). The duration to walk from the 3-meter mark to the 8-meter mark was measured in both conditions and the speed (m/s) was calculated. In the balance test, participants were asked to balance on either their left or right leg with their eyes open and hands crossed over their chest; the time they were able to maintain balance in this position was measured (Springer et al., 2007). The time begins when they raise their foot and ends when participants attempt to regain their balance by (1) using their arms, (2) placing their raised foot down, or (3) shifting the weight bearing foot. The test also ended when they were able to maintain their balance for the maximum duration of 30s.

Data Analysis

A 2 times (pre vs. post) × 2 groups (online vs. in-person) mixed ANOVA was conducted on the TMT scores and PAGEQ subscale scores. Paired t-test was conducted on each physical assessment score. As the sample size of the online group was limited, the results of the 2-way mixed ANOVA and paired *t*-test were confirmed by using robust statistics (Field & Wilcox, 2017).

RESULT AND DISCUSSION

Executive Function

Descriptive statistics of the TMT-B to TMT-A (B/A) ratio score are presented in Figure 1. A 2 times (pre vs. post) × 2 groups (online vs. in-person) mixed ANOVA on the B/A ratio score indicated that interaction effects were significant ($F[1,22] = 4.35$, $p = .049$, $\eta_{p2} = .17$). This result was also confirmed with robust statistics ($F_{robust}[1,16.3] = 5.09$, $p = .038$). Post-hoc tests revealed that for the in-person group, the B/A ratio score at post ($M = 2.48$, $SD = 0.80$) was significantly higher than at pre ($M = 2.03$, $SD = 0.89$), whereas the B/A ratio scores slightly decreased over time for the online group (pre: $M = 2.28$, $SD = 0.69$; post: $M = 1.90$, $SD = 0.61$).

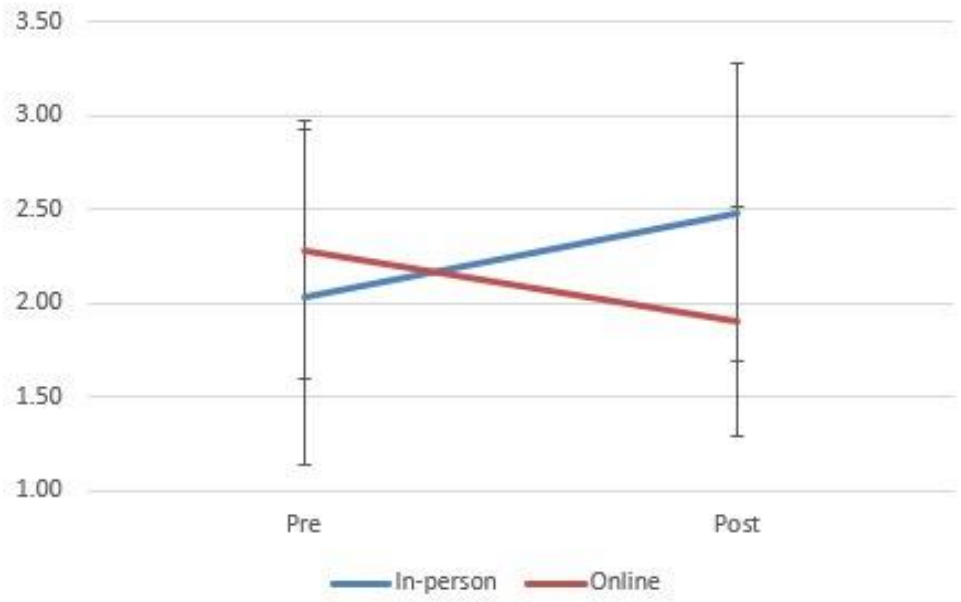
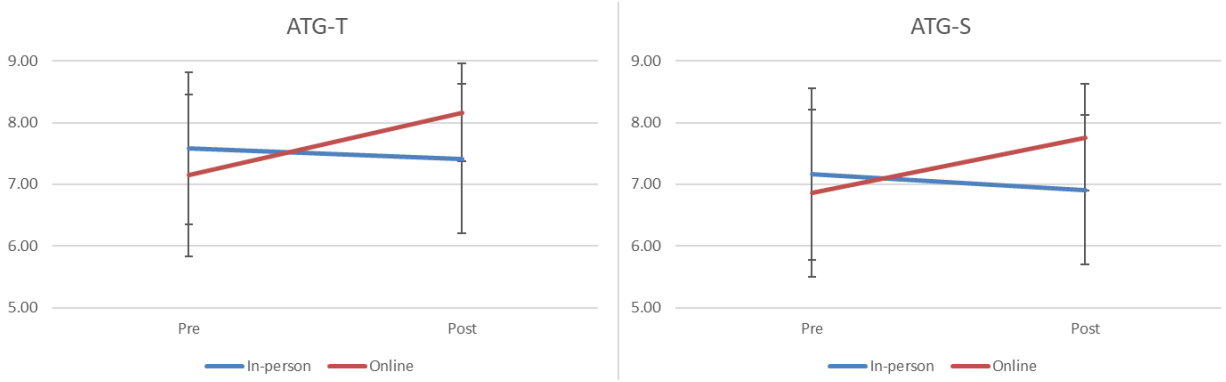


Figure 1. The Ratio Score of The Trail Making Test in In-Person and Online Square Stepping Exercise Groups. *Note*. Error bar: *SD*.

Group Cohesion

Figure 2 shows the averaged two PAGEQ subscale scores in online and in-person SSE groups. A 2 times (pre vs. post) × 2 groups (online vs. in-person) mixed ANOVA on each of the PAGEQ subscale scores indicated that interaction effects were significant on Individuals Attractions to the Group–Task (ATG-T: $F[1,22] = 5.08$, $p = .034$, $\eta_{p2} = .19$) and –Social (ATG-S: $F[1,22] = 4.95$, $p = .037$, $\eta_{p2} = .18$). Post-hoc tests revealed that ATG-T and ATG-S scores significantly increased over time for the online group (see Figure 2). These results were mirrored with robust statistics.



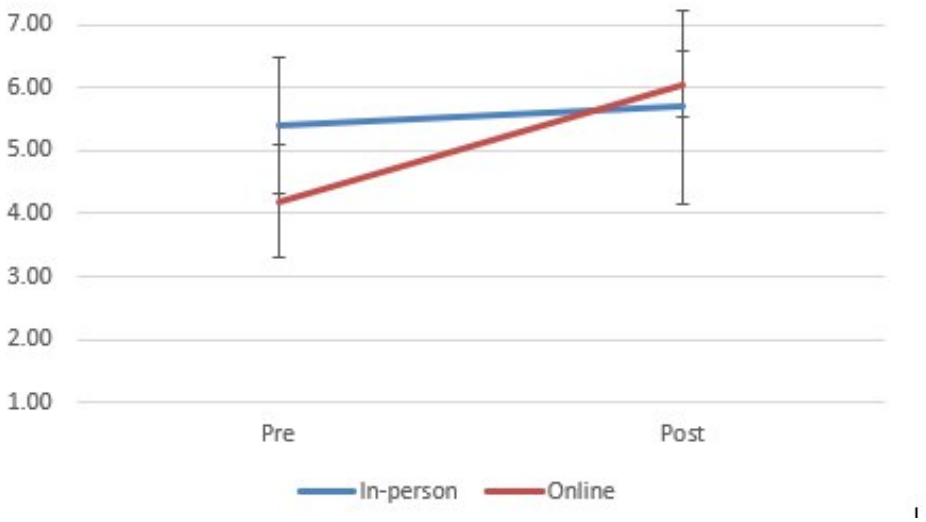
Note: ATG-T: Individual Attractions to the Group—Task; ATG-S: Individuals Attractions to the Group—Social. Error bar: SD.

Figure 2. The Averaged Subscale Scores of the Physical Activity Group Environment Questionnaire in In-Person and Online Square Stepping Exercise Groups.

Subjective Vitality

Figure 3 shows the SVS scores in online and in-person SSE groups. A 2 times (pre vs. post) × 2 groups (online vs. in-person) mixed ANOVA on the vitality score indicated that interaction effects ($F[1,22] = 4.95$, $p = .037$, $\eta_{p2} = .18$) and the main effect of time ($F[1,22] = 9.32$, $p = .006$, $\eta_{p2} = .30$) were significant. Post-hoc tests revealed that online group's vitality score at pre ($M = 4.20$, $SD = 1.55$)

was significantly lower than in-person group's vitality score (M = 5.40, SD = 1.09). However, online group's vitality score significantly increased over time (post: M = 6.06, SD = 0.53) although in-person's vitality score did not change over time (post: M = 5.69, SD = 0.90). These results were not exactly mirrored with robust statistics. The main effect of time was significant (F_{robust}[1,18.9] = 9.52, p = .006), but interaction effects were marginally significant (F_{robust}[1,18.9] = 3.88, p = .064).



Note: Error bar: *SD*.

Figure 3. Subjective Vitality Scores in In-Person and Online Square Stepping Exercise Groups

The present study aimed to investigate the short-term effects of a home-based online SSE on cognitive and social functions in sedentary older adults. The study was done amid the COVID-19 pandemic, and the home-based online SSE was carried out under tighter safety regulations. To that end, the effects of the online SSE on cognitive and social functions were compared to the in-person SSE.

Results revealed that for the in-person group, the TMT-B to TMT-A (B/A) ratio score at post was significantly higher than at pre, whereas the B/A ratio scores slightly decreased over time for the online group. Arbuthnott and Frank (2000) reported that a) the B/A ratio score was positively associated with the speed of set-switching performance, and b) participants with a low B/A ratio (e.g., B/A < 2; 2 < B/A < 3) were faster to complete set-switching tasks, compared to those with a B/A ratio over 3. They also stated that the B/A ratio score may be the best indicator of executive control function. Based on the finding of the present study, the home-based online SSE under higher quality of exercise instruction was considered effective to enhance executive function such as cognitive flexibility in sedentary older adults. Such enhancement was not observed in the in-person SSE group as the quality of exercise instruction was not consistent over the 7-week intervention period. Kawabata et al. (2021) reported that SSE conducted online was effective to enhance executive function measured by Modified Card Sorting Task (Caffarra et al., 2004) in sedentary young adults. Despite the difference in tests between their study and the present study, the similar findings of these two studies suggest that the enhanced executive function seen in the SSE condition might be caused by the cognitive challenges involved in SSE.

In the present study, personal involvement with the group task (ATG-T) and social interaction with their group (ATG-S) in the online SSE group significantly enhanced over the 3-week intervention period. However, these enhancements were not observed in the in-person SSE group. These differences in group cohesion scores might be attributed to the differences in the environments where SSE sessions were conducted. In the online SSE group, participants consisted of pairs (e.g., couples, sisters, or friends) that were the same across the intervention period. On the other hand, participants in the in-person SSE group were divided to three or four groups of five individuals in every session and the group members were not the same all the time over the intervention period. Furthermore, the instructor for the in-person group was changed several times due to the lack of manpower at the sport center. Thus, it might be difficult for the participants in the in-person group to promote group cohesion over time. These differences in the environments where SSE sessions were conducted were also considered to be

associated with the results that online group's vitality score significantly improved over time whereas in-person's vitality score did not change over time. Kawabata et al. (2021) reported that sedentary young adults perceived that social communication with their group (ATG-S) and bonding and closeness existing in their group (GI-T) were significantly higher in the online SSE condition, compared to the active control condition. The consistent findings of the present study and Kawabata et al. (2021) indicated that it is possible to promote different aspects of group cohesion such as individual involvement with the exercise task and social interactions with other group members in the online SSE sessions, whereas they were not physically at the same site.

CONCLUSION

In the current study, SSE was carried out online and found to be successful to improve executive function and group cohesion in sedentary older adults. These results were consistent with Kawabata et al.'s (2021) study conducted for sedentary young adults. Furthermore, the effects of the online SSE were compared to the in-person SSE. The novel online method and results are the strong points of the present study. Despite the strengths, there are also limitations to the present study. For instance, the number of participants and the duration of the intervention in the online SSE was smaller and shorter compared to the in-person SSE because the online SSE sessions were conducted under tighter safety regulations of the coronavirus pandemic. Furthermore, physical assessment was not conducted for the online SSE group due to tighter safety regulations. The in-person group demonstrated a significant improvement in their left leg balance duration. However, it was not possible to examine whether the same effect occurred for the online SSE group.

Individuals aged 60 years and over are more vulnerable to the coronavirus and at higher risk of leading serious conditions (World Health Organization, 2020). Given the coronavirus pandemic circumstance, it was valuable to explore the option of the online SSE method for older adults. Therefore, its short-term effects were examined in the present study. The long-term effects of the online SSE on cognitive, physical, psychological, and social functioning should be addressed in older adults in future research.

ACKNOWLEDGEMENT

The study was financially supported by Ministry of Education Academic Research Fund Tier 2 Grant (Project No.: MOE2019-T2-1-019). The views expressed in this paper are the authors' and do not necessarily represent the views of Singapore Ministry of Education.

The authors thank participants for their time. Without their voluntary participations, this study would not have been possible.

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