RESEARCH ARTICLE

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Effects of smartphone application-based cognitive training at home on cognition in community-dwelling non-demented elderly individuals: A randomized controlled trial

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Abstract

Introduction: We investigated whether cognitive function improves in elderly individuals after Application-based Cognitive Training at Home (ACTH) for 12 months.

Methods: A total of 389 non-demented elderly volunteers aged over 60 years were recruited and randomly assigned to the intervention or control group. The intervention group underwent daily ACTH (with regular feedback from the administrator) and monthly offline cognitive training in groups for 12 months. All participants received a computerized cognitive test battery called Inbrain Cognitive Screening Test (Inbrain-CST) at baseline and 6 and 12 months. The primary outcome was the change in the total composite score of Inbrain-CST, and secondary outcomes included changes in composite scores in five cognitive domains of Inbrain-CST.

Results: The intervention group outperformed the control group in terms of the total score ($P = .001$) and subscores of language ($P < .001$) and memory ($P < .001$) domains at 12 months.

Discussion: ACTH improved global cognition in community-dwelling non-demented elderly individuals.

KEYWORDS
cognitive training, home training, intervention, smartphone

1 | INTRODUCTION

Cognitive decline and dementia have been increasingly considered important public health concerns. As there are no curable treatments for dementia, which is most commonly attributed to Alzheimer's disease (AD), numerous types of interventions that could help maintain cognition in cognitively healthy elderly individuals have been examined. Cognitive training interventions have been tested in terms of their effectiveness to prevent cognitive decline, because mental activity contributes to cognitive reserve[1,2] and thus reduces the risk of dementia development.

Indeed, many studies have demonstrated the positive effect of cognitive interventions on cognition.[3] However, previous studies, including Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE), one of the largest randomized controlled trials (RCT), applied interventions in a small group setting by a certified trainer.[4–6] Furthermore, these intervention programs were limited due to money, time, and space requirements in real clinical circumstances. From this

perspective, home-based cognitive interventions may be an alternative strategy because of their feasibility. In fact, one previous RCT from Korea revealed that cognition in patients with amnestic mild cognitive impairment (MCI) improved significantly after 12 weeks of home cognitive intervention.[7] Although that study suggested the efficacy of home-based cognitive intervention, this type of intervention still requires paper-and-pencil materials and it is difficult to monitor compliance of all participants. Another famous RCT of multidomain intervention to prevent cognitive decline (the Finnish Geriatric Intervention Study to Prevent Cognitive Impairment and Disability [FINGER] study)[8] applied personal computer-based training at home; however, this may not be practical because many elderly individuals in Korea do not use computers at home. In addition, most previous studies, except the FINGER study, provided cognitive intervention for a relatively short period of time (maximum 6 months).[3] Cognitive intervention would be more effective if it could be of longer duration, according to the hypothesis that positive effects of intervention may accumulate to increase cognitive reserve and enhance brain plasticity.[1,9] Therefore, an easily accessible way of cognitive training should be developed and tested in a large cohort of elderly individuals.

Here, we investigated the effectiveness of smartphone application-based cognitive intervention (with monthly group cognitive training and encouragement for lifestyle modification as an ancillary program) for 1 year in community-dwelling non-demented elderly individuals. More specifically, 30-minute digitally designed homework per day was delivered via smartphone, 5 times per week for 1 year and participants responded via smartphone. It was, therefore, possible for investigators to monitor the daily performance of participants. The number of smartphone users is increasing even among the elderly population, and it has become an important part of daily life. Smartphone applications are commonly used by elderly individuals and are easily accessible any time, which led to increased compliance in the study. Therefore, if this study proves positive effects on cognitive improvement, it may help health-care providers plan future cognitive intervention programs on a community basis.

2 | METHODS

2.1 | Study design

This Application-based Cognitive Training at Home (ACTH) study was a single-center, randomized, single-masked, and parallel group study with the aim to investigate the effect of smartphone application-based cognitive training on cognition in community-dwelling elderly individuals. This study was conducted between March 2018 and August 2019 at Gangnam Dementia Center in Seoul, South Korea. This trial was registered at "ClnicalTrials.gov" as NCT03494699.

2.2 | Participants

We recruited community-dwelling non-demented volunteers at Gangnam Center for Dementia in Seoul, South Korea. This public facility

RESEARCH IN CONTEXT

1. **Systematic Review**: The authors reviewed the studies archived in PubMed to investigate the benefit of cognitive intervention and to identify previous trials in which mobile application-based cognitive training was used. While some large randomized controlled trials (RCTs) have reported the benefits of cognitive intervention, there have been no RCTs that used a mobile-phone application for cognitive training.

2. **Interpretation**: This RCT, which included 387 community-dwelling elderly individuals, showed that global cognition improved after smartphone Application-based Cognitive Training at Home (ACTH) intervention was provided for 12 months. Thus, our study suggested that smartphone applications can be efficiently used as tools of cognitive training.

3. **Future Directions**: This study provides evidence for clinicians to prescribe ACTH for the prevention of dementia; ACTH is more advantageous than conventional pencil-and-paper or computer-based cognitive training because smartphones have become an indispensable part of daily life. Additional studies may (1) identify the populations likely to benefit the most and (2) evaluate the structural or functional brain changes associated with ACTH.

HIGHLIGHTS

- We investigated effects of smartphone App-based Cognitive Training at Home (ACTH).
- 30-min digitally designed homework was delivered via smartphone daily for 1 year.
- This randomized trial demonstrated that ACTH improves cognition in normal elderly.

focuses on integrated dementia management by providing services including early screening, dementia prevention education, cognitive rehabilitation programs, and treatment support.

The following inclusion criteria were applied: (1) individuals ≥60 years old; (2) literate with education years of 6 or higher; (3) Korean version of Mini-Mental State Examination (K-MMSE) score >23[10]; (4) preserved activities of daily living (ADL), as defined by Korea Instrumental ADL ≤5[11]; (5) no major neurological and psychiatric disorders affecting cognition or diagnosis of dementia; and (6) personal Android smartphone users for the purpose of using cognitive training application. Participants with the following conditions were excluded from the study: (1) major cardiovascular events such as stroke or myocardial infarction in the past 3 months, (2) severe or unstable medical disease

(with expected life expectancy <2 years) that could interfere with successful study completion; (3) severe hearing difficulty or visual disturbance, (4) limitation in communication,; (5) previous dementia diagnosis, (6) plan for immigration or moving within 1.5 years after study enrolment, (7) finished cognitive training session in this center within 6 months of study enrolment.

Written informed consent was acquired from all participants and the study protocol was approved by the Institutional Review Board of the Samsung Medical Center (IRB No. 2018-02-050)

2.3 | Randomization

Consecutively recruited participants were randomly assigned to the intervention or control group. Randomization was stratified according to age (three age categories, ≥60 and <70, ≥70 and <80, and ≥80) and sex in a 1:1 ratio. Details are described in the supporting information.

2.4 | Intervention

The intervention group experienced comprehensive multidisciplinary intervention, mainly focusing on cognitive training using a smartphone application at home. The intervention consisted of the following protocol: (1) four education sessions (2 hours for 4 days) at the beginning of the study; (2) ACTH, 5 days per week for 12 months; (3) lifestyle monitoring of participants via questionnaires on smartphones that appeared 4 times a week before they started the ACTH; and (4) a 90-minute face-to-face cognitive intervention in groups of 5 to 10 people, monthly for 12 months.

First, the initial education sessions were modified from the educational program that had already been included in the regular service of Gangnam Center for Dementia. It comprised a lecture about dementia, lifestyle management related to cognitive health,[12] and a demo-version of group cognitive intervention.

Second, the ACTH used a smartphone cognitive training application named Inbrain-Trainer that included a total of 10 cognitive training tasks that covered six cognitive domains. Inbrain-Trainer is described in detail in https://www.midasit.com/img/part/inbrainTrainer_2018.pdf and Table S1 in supporting information. Under the supervision of a neuropsychologist, the clinical trial coordinator assigned homework consisting of two sets of three different cognitive domain tasks per day, 5 days per week, for 12 months. Participants could complete the daily homework in ≈20 to 40 minutes. Attendance, time duration that participants spent doing the homework, and their scores were automatically sent to the administration's website; therefore the instructor could monitor performance and compliance of all participants in this study.

Third, regarding lifestyle monitoring via smartphone, when participants logged in to the homework session, they completed a short questionnaire about their lifestyles. Participants' responses were also sent to the administration's website, and research assistants called participants biweekly to encourage moderation in drinking, healthy diets, smoking cessation, and exercise.[12]

Fourth, the monthly offline cognitive intervention in groups aimed to guide individual application-based training and check progress in homework. The number of participants per group was 5 to 10, with a maximum number of 12 participants per group. Detailed explanation of the study method is described in the supporting information.

2.5 | Outcomes

Cognitive assessments and administration of self-reported questionnaires were conducted at baseline, 6 months, and 12 months after completion of the 12-month intervention. Cognition was assessed by two independent psychometricians who were blinded to participants' interventions, using a tablet-based cognitive test battery called Inbrain Cognitive Screening Test (Inbrain-CST, Table S2 in supporting information) developed by MIDAS IT and Samsung Medical Center. Inbrain-CST consisted of tests for five cognitive domains. The composite score for each cognitive domain was calculated based on multiple factor analysis (MFA).[13]

The primary outcome measure was the total composite score of Inbrain-CST. Secondary cognitive outcome measures included composite scores for five cognitive domains on Inbrain-CST and scores for individual memory tests including immediate recall, delayed recall, and recognition scores. Other secondary outcome measures included modified versions of Multifactorial Memory Questionnaire (MMQ) subscales for satisfaction, ability, and strategy; Prospective and Retrospective Memory Questionnaire (PRMQ);[14,15] short version of the Geriatric Depression Scale (GDS15); Geriatric Anxiety Inventory (GAI);[16,17] Perceived Stress Scale (PSS); brief version of World Health Organization Quality of Life (QOL) assessment questionnaire (WHOQOL-brief);[18,19] and a questionnaire about cognitive healthy behaviors including (1) physical activity (0 to 20), (2) cognitive activity (0 to 20), and (3) social activity (0 to 20). Details of these questionnaires are described in Table S3 in supporting information.

2.6 | Statistical analysis

An experienced statistician (S.K.) calculated the sample size based on the results from a previous pilot study recruiting 26 normal controls who scored 59.5 ± 10.7 as total composite score on Inbrain-CST. We conservatively assumed that the correlation coefficient between scores at baseline and at 12 months was 0. Under the hypothesis that the standard deviation of scores (at baseline or 12 months and in the control or intervention group) was 15, and the difference between changes of total score (from baseline to 12 month) of the two groups was five, 142 participants were required for each study group with a significance level set at 0.05 and with a power of 80% to detect a significant difference. Assuming a dropout rate of about 30% based on a previous cognitive intervention study in Korea,[7] the final sample size was calculated as 400, with 200 participants per group.
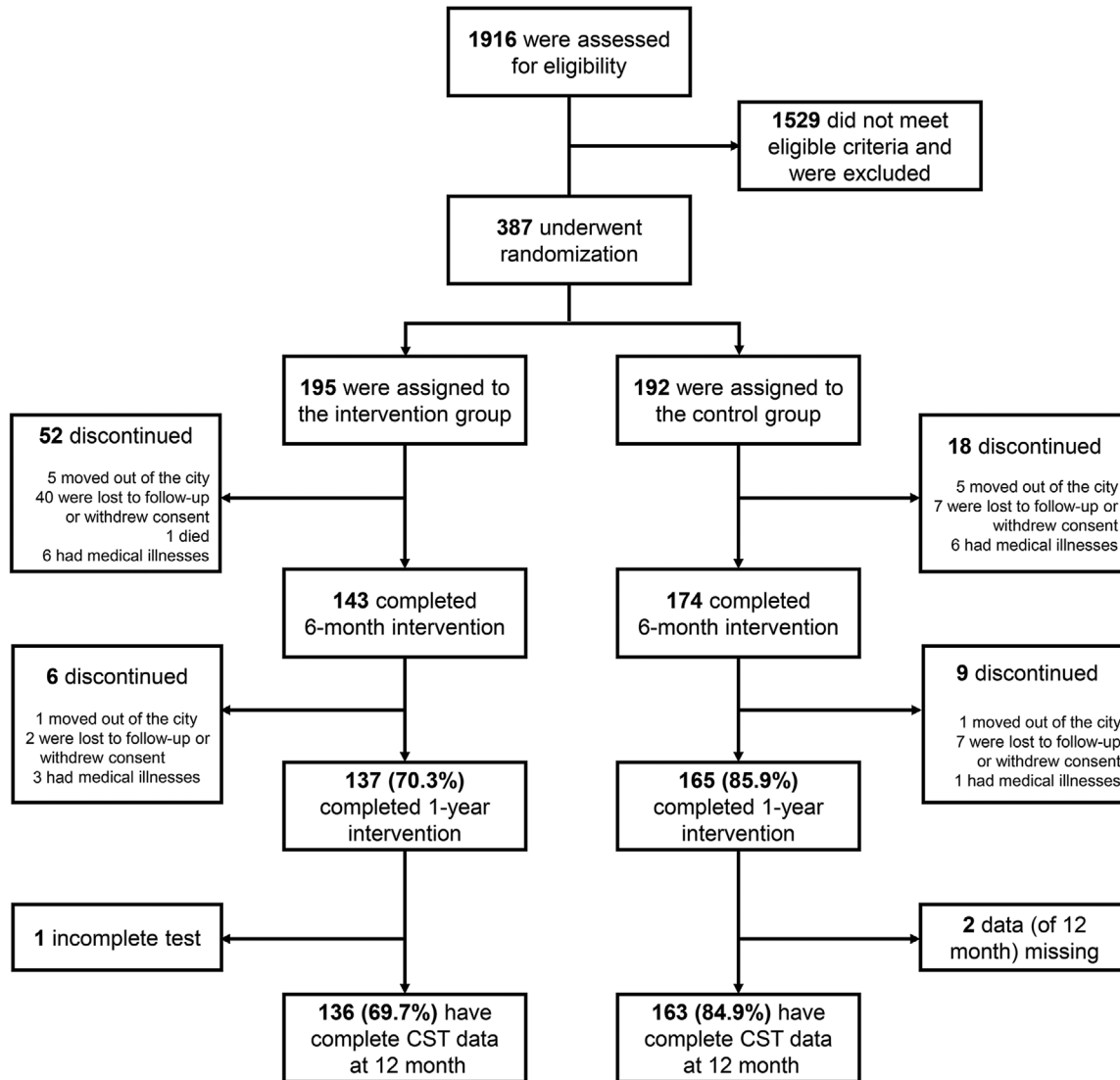
FIGURE 1 Enrolment, randomization, and follow-up. CST, Cognitive Screening Test

All analyses were based on intention-to-treat analyses. The main analysis included a comparison of the change in the primary outcome measure from baseline to 12 months between the intervention and control groups. We also compared the change in the primary outcome measure from baseline to 6 months between the intervention and control groups. Secondary analyses included comparison of the change in all secondary outcome measures from baseline to 6 months and from baseline to 12 months between the intervention and control groups. We used linear mixed-model analysis to address the issue of missing data. Fixed effects included baseline age; education years; sex; group (intervention vs. control); visit (baseline, 6, and 12 months), which was considered a categorical variable; and group-by-visit interaction. We used a random-effects model to explain repeated measures within patients. All tests of effects were conducted at a two-sided alpha of 0.05. All statistical analyses were performed using STATA version 15.0 (Stata Corporation).

3 | RESULTS

3.1 | Participants' flow, adherence to interventions, and background characteristics

A total of 1916 elderly dwellers in Gangnam-gu were screened for eligibility in this study, and finally, 387 participants were randomly enrolled. Figure 1 shows the flow from screening to follow-up of study participants. A total of 195 participants were assigned to the intervention group, and 192 participants were assigned to the control group. After withdrawal from consent, loss to follow-up, discontinuation due to protocol violation (because of moving or medical illness), or death, 302 participants (77%) completed the 1-year intervention program. Among them, final Inbrain-CST data from three participants were missing or incompletely obtained. Therefore, primary outcome measures were available for 136 (69.7%) individuals from the intervention group and
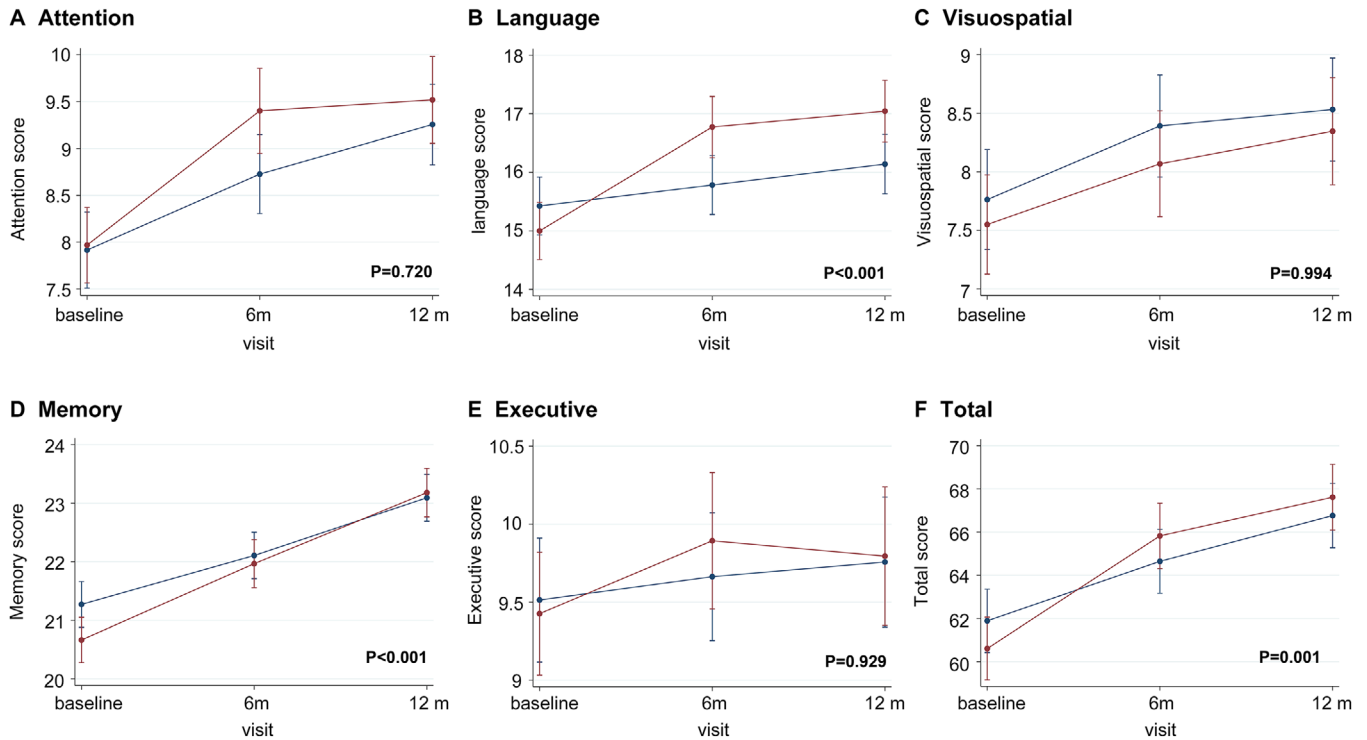
A Attention

B Language

C Visuospatial

D Memory

E Executive

F Total

FIGURE 2 Changes in cognitive outcome at 6 and 12 months of cognitive intervention (red, intervention group; blue, control group)

for 163 (84.9%) from the control group. The average task performance rate on the application (performed task/total homework task) throughout the study period was 83.8% for 136 participants. The mean number of offline sessions that each volunteer participated in was 10.4/12. Baseline characteristics were balanced between the intervention and control groups, as there were no significant differences in age, sex, education, comorbidities, cognitive scores, and scores on depression and anxiety scales (Table 1).

3.2 | Intervention effects on cognitive performance

The effect of the intervention on cognitive outcome measures is shown in Table 2 and Figure 2. Both the control and the intervention groups showed increase in total and five other cognitive composite scores at 6 and 12 months of intervention, which was the primary outcome in this study. When the group-by-visit interaction effect was investigated as a primary analysis, the intervention group showed a larger increase in total scores than the control group both at 6 months ($P < .001$) and 12 months ($P = .001$). Specifically, the intervention group showed a larger increase in language ($P < .001$ both at 6 and 12 months) and memory composite scores ($P = .006$ at 6 months, $P < .001$ at 12 months). There was no significant difference in changes at 12 months in attention ($P = .72$), visuospatial ($P = .994$), and executive composite scores ($P = .929$) between the intervention and the control groups. However, the intervention group showed a tendency to have a larger increase in attention score ($P = .05$) at 6 months of intervention compared to the control group.

3.3 | Intervention effects on self-reported measures

The effect of the intervention on MMQ, PRMQ, GDS15, GAI, PSS, WHOQOL, and self-reported amount of physical activity, cognitive activity, and social activity is shown in Table 3. The intervention group had a larger increase in MMQ-satisfaction ($P = .001$) and MMQ-ability scores ($P = .035$) compared to the control group, at 12 months of intervention. Among reported cognitive healthy lifestyles, the interaction effect of group-by-visit on amount of cognitive activity was significant ($P < 0.001$ for both at 6 and 12 months), which suggested that the intervention group showed a significant increase in cognitive activity during the study compared to the control group. The intervention group showed a tendency to have a larger increase in PSS ($P = .069$), WHOQOL-brief scores ($P = .060$), and amount of social activity ($P = .057$) at 12 months, statistical significances of which were marginal.

4 | DISCUSSION

Our ACTH study was an RCT that investigated the effect of smartphone application-based cognitive training on cognition in community-dwelling non-demented elderly individuals. This RCT involving as many as 400 people is distinguishable from previous studies. First, our cognitive intervention was performed via mobile phones. Mobile phones may be advantageous over desktop or laptop computers in terms of cognitive training, because not only the number of smartphone users

TABLE 1 Baseline characteristics of study participants

	Control group (n = 192)	Intervention group (n = 195)	P
Age, years	70.5 ± 5	70.8 ± 4.8	.567
Female (%)	141 (73.4)	144 (73.9)	.927
Education, years	14.2 ± 3	14.2 ± 3	.817
Comorbidities			
Hypertension	57 (29.69)	74 (37.95)	.086
Diabetes	15 (7.81)	25 (12.82)	.106
Hyperlipidemia	77 (40.1)	84 (43.08)	.553
Cardiac disease	13 (6.77)	20 (10.26)	.220
Stroke	2 (1.04)	4 (2.05)	.422
Baseline cognition[a]			
MMSE	28.4 ± 1.4	28.3 ± 1.6	.806
CST total score	61.4 ± 10.1	60.4 ± 10	.550
CST attention score	7.8 ± 2.9	7.9 ± 3	.130
CST language score	15.3 ± 3.1	15 ± 3.2	.898
CST visuospatial score	7.6 ± 3.1	7.5 ± 3.3	.791
CST memory score	21.2 ± 2.6	20.6 ± 2.8	.278
CST executive score	9.4 ± 2.9	9.4 ± 2.4	.350
K-IADL	0.3 ± 0.7	0.3 ± 0.7	.613
GDS15	2.6 ± 2.8	2.7 ± 3.2	.724
GAI	5.3 ± 5.6	4.7 ± 5.3	.263

Abbreviations: CST, Cognitive Screening Test; GAI, Geriatric Anxiety Inventory; GDS15, short version of the Geriatric Depression Scale; K-IADL, Korean-instrumental activity of daily living; MMSE, Mini-Mental Status Examination.
Note: Comparison of baseline cognition was conducted by analysis of covariance after adjusting for age, sex, and education.

is rapidly increasing, but mobile phones are also readily accessible throughout the day, regardless of where people are located. Second, our smartphone application platform enabled us to monitor participants' daily performances, which in turn was important in encouraging them to do their homework. The average homework performance rate of our intervention group reached 83% throughout the study period. Third, the duration of our cognitive intervention was longer than other studies.

The first major finding of our study was that global cognition (measured as total score on Inbrain-CST) improved in the intervention group at 12 months of intervention. Inbrain-CST is a computerized cognitive screening test that our group has developed and validated. This cognitive test battery consists of 13 tasks encompassing five major cognitive domains, which have been adopted from widely used conventional neuropsychological tests. The total score—the primary outcome measure in this study—was developed using the MFA,[13] which generates a more balanced composite score considering all task scores, compared to a simple summation. Therefore, we consider that global cognition is well represented, and the significantly larger increase in total score in the intervention group proves the effect of this intervention.

The second major finding was that our analyses revealed significant group-by-time interactions in memory and language composite scores, but not in attention, visuospatial, and executive composite scores. We expected that application-based cognitive training could improve attention or executive function because smartphone usage requires motor coordination and processing speed, and a task that stimulates a certain cognitive domain could enhance cognition in similar domains (near-transfer effects).[5,20] However, the intervention and control groups did not significantly differ in attention and executive functions. A possible explanation for negative results could be a ceiling effect, such that our eligible participants who had been using smartphones for years may have had a high level of attention/executive function. Alternatively, the control group might have done intervention-like activities in their daily life (= contamination bias, which is commonly found in community intervention trial) that potentially caused the intervention effect toward null.

The positive effects on memory and language domains are noteworthy because memory decline (including working, short-term, and long-term memory) and difficulty in naming are common complaints of the elderly, regardless of their cognitive status. Previous studies involving computerized cognitive intervention also determined that healthy participants showed significant improvement on memory domain at least compared to inactive controls,[21] but not compared to active controls.[22] Regarding the benefits that our participants received from cognitive intervention, however, we should consider confounding factors such as learning effects or the bias from single blindness. That is, cognitive improvement in the intervention group might have partially resulted from the practice effects as daily cognitive activities were

TABLE 2 Cognitive outcomes at 6 and 12 months of cognitive intervention

| | | Control group | Intervention group | Intervention effect (group × visit) | |
				Coef (SE)	P
Total score	Baseline	61.4 ± 10.1	60.4 ± 10	Ref	
(Primary outcome)	6 M	64.2 ± 9.8	66.6 ± 10	2.518 (0.568)	<.001
	12 M	66.5 ± 9.7	68.8 ± 9.7	1.899 (0.582)	.001
Attention score	Baseline	7.8 ± 2.9	7.9 ± 3	Ref	
	6 M	8.6 ± 2.7	9.4 ± 2.7	0.614 (0.314)	.05
	12 M	9.2 ± 2.8	9.5 ± 2.5	0.115 (0.321)	.72
Language score	Baseline	15.3 ± 3.1	15 ± 3.2	Ref	
	6 M	15.7 ± 3.4	17 ± 3.3	1.327 (0.245)	<.001
	12 M	16.1 ± 3.1	17.4 ± 3.5	1.231 (0.251)	<.001
Visuospatial score	Baseline	7.6 ± 3.1	7.5 ± 3.3	Ref	
	6 M	8.3 ± 2.6	8.2 ± 2.9	−0.058 (0.211)	.782
	12 M	8.5 ± 2.4	8.6 ± 2.6	0.002 (0.216)	.994
Memory score	Baseline	21.2 ± 2.6	20.6 ± 2.8	Ref	
	6 M	22 ± 2.7	22.2 ± 2.6	0.519 (0.189)	.006
	12 M	23.1 ± 2.5	23.5 ± 2.4	0.731 (0.193)	<.001
Executive score	Baseline	9.4 ± 2.9	9.4 ± 2.4	Ref	
	6 M	9.5 ± 2.8	9.9 ± 2.5	0.31 (0.265)	.242
	12 M	9.7 ± 2.9	9.8 ± 2.6	0.024 (0.271)	.929
Immediate recall	Baseline	18.7 ± 3.1	18.2 ± 3.2	Ref	
	6 M	20 ± 3.4	20.4 ± 3.4	0.708 (0.309)	.022
	12 M	22.5 ± 3.2	23.1 ± 3.3	0.964 (0.316)	.002
Delayed recall	Baseline	6.7 ± 1.9	6.4 ± 2.2	Ref	
	6 M	7.2 ± 1.7	7.4 ± 1.8	0.322 (0.156)	.039
	12 M	7.9 ± 1.7	8 ± 1.7	0.234 (0.159)	.141
Recognition	Baseline	22.7 ± 3.2	22 ± 3.3	Ref	
	6 M	23.3 ± 3.1	23.4 ± 3.1	0.496 (0.286)	.083
	12 M	23.5 ± 3.2	24.1 ± 2.9	0.945 (0.293)	.001

Abbreviations: Coef, coefficient; M, months; SE, standard error.

Note: P for interaction (group × visit) from linear mixed-model analysis including baseline age, education years, sex, group, visit, group, and group × visit interaction as fixed effects.

performed on the smartphone and as the cognitive testing was conducted using a tablet, both of which share activities with a similar digital environment. Also, as the blinding to participants was not possible, the intervention group may have been more effortful to other cognitive activities and lifestyle modifications, which may have contributed to the positive results obtained during cognitive testing.

A few clinical trials have used smartphone applications as cognitive training tools. A previous study from Korea investigated the effect of 8-week smartphone application training on cognitive improvement in 53 subjective memory complaints, and concluded that working memory score improved significantly in the intervention group compared to the control group.[23] However, this study included only 53 participants and the duration of intervention was 8 weeks, which was not long enough to examine long-term effects. In accordance to previous studies' suggestion that longer periods of training may be beneficial, our study is

the first to apply smartphone application-based cognitive training for an extended time period (12 months).

The third major finding of our study was that compared to the control group, the intervention group reported significantly higher MMQ-satisfaction score and amount of cognitive activity after 12 months of intervention. These improvements cannot be explained just by changes in mood or lifestyle, because changes in GDS or QOL scores did not differ between the intervention and the control groups. Rather, higher MMQ-satisfaction scores may indicate higher satisfaction with one's own subjective memory ability, which is important considering that subjective memory complaints possibly predict objective cognitive decline, although biomarker investigation is needed to predict prognosis.[24–28] In addition, lower satisfaction about self-memory leads to depressive mood,[29] which is closely related with cognitive impairment or lower quality of life in the elderly.[30–32] Of note, the

TABLE 3 Secondary outcomes at 6 and 12 months of cognitive intervention

		Control group	Intervention group	Intervention effect (group × visit) Coef (SE)	P
MMQ-satisfaction (0–36)	Baseline	21.3 ± 6.4	21.6 ± 6.9	Ref	
	6 M	22 ± 7	22.5 ± 6.8	0.364 (0.514)	.479
	12 M	22.4 ± 6.8	24.4 ± 6.9	1.698 (0.524)	.001
MMQ-ability (0–40)	Baseline	25.3 ± 6.8	26.1 ± 7.2	Ref	
	6 M	25.8 ± 7.1	26 ± 7.6	−0.294 (0.59)	.618
	12 M	25.3 ± 7.1	27.3 ± 7.4	1.263 (0.6)	.035
MMQ-strategy (0–38)	Baseline	17.7 ± 7.1	17 ± 7.1	Ref	
	6 M	17.6 ± 7	17.3 ± 7.9	0.232 (0.673)	.730
	12 M	18.2 ± 7.1	18.5 ± 7.7	0.893 (0.686)	.193
PRMQ-total (16–80)	Baseline	31.8 ± 9.2	31.1 ± 10	Ref	
	6 M	31.2 ± 9.6	30.5 ± 10.2	−0.421 (0.719)	.558
	12 M	32.1 ± 9.6	30.5 ± 10.3	−0.999 (0.732)	.173
GDS (0–15)	Baseline	2.6 ± 2.8	2.7 ± 3.2	Ref	
	6 M	2.5 ± 2.8	2.8 ± 3.4	0.235 (0.25)	.348
	12 M	2.5 ± 3.1	2.5 ± 3.1	0.048 (0.255)	.851
GAI (0–20)	Baseline	5.3 ± 5.6	4.7 ± 5.3	Ref	
	6 M	5 ± 5.6	4.7 ± 5.2	0.166 (0.392)	.671
	12 M	5 ± 5.6	4.4 ± 5.2	0.246 (0.399)	.538
PSS (10–50)	Baseline	26.5 ± 5	26.6 ± 5	Ref	
	6 M	26.7 ± 4.5	26.3 ± 5	−0.598 (0.487)	.220
	12 M	26.5 ± 4.7	25.7 ± 4.6	−0.904 (0.497)	.069
WHOQOL (26–130)	Baseline	90.4 ± 13.3	90.2 ± 13.7	Ref	
	6 M	90.2 ± 13.7	90.3 ± 13.9	0.582 (0.89)	.513
	12 M	90.1 ± 13.6	92 ± 14.6	1.704 (0.905)	.060
Physical activity	Baseline	9.9 ± 4	10.1 ± 3.8	Ref	
	6 M	9.9 ± 4.1	10.8 ± 3.9	0.549 (0.339)	.105
	12 M	10 ± 3.9	10.8 ± 4	0.414 (0.344)	.229
Cognitive activity	Baseline	7.4 ± 3.7	7.3 ± 3.7	Ref	
	6 M	7.3 ± 3.6	8.7 ± 3.4	1.365 (0.323)	<.001
	12 M	7.1 ± 3.2	8.8 ± 3.6	1.561 (0.329)	<.001
Social activity	Baseline	6.9 ± 3	6.9 ± 2.9	Ref	
	6 M	6.9 ± 2.7	7.4 ± 3.1	0.349 (0.278)	.209
	12 M	7 ± 2.7	7.7 ± 3.2	0.538 (0.283)	.057

Abbreviations: Coef, coefficient; GAI, Geriatric Anxiety Inventory; GDS15, short version of the Geriatric Depression Scale; M, month; MMQ, Multifactorial Memory Questionnaire; PRMQ, Prospective and Retrospective Memory Questionnaire; PSS, Perceived Stress Scale; se, standard error; WHOQOL, brief version of World Health Organization Quality of Life assessment questionnaire.

Note: P for interaction (group × visit) from linear mixed-model analysis including baseline age, education years, sex, group, visit, group, and group × visit interaction as fixed effects.

intervention group reported a significantly higher level of cognitive activity. Although various tools have been used for cognitive training, no specific cognitive training method has been routinely recommended due to their unavailability. Taken together, our study suggested that smartphone application training combined with intermittent group training and lifestyle modification can be used efficiently to improve cognitive activity in non-demented elderly individuals.

This study's major strength is that this is the first RCT that recruited as many as 400 non-demented participants from a community center and investigated whether their cognitive function improved after receiving application-based cognitive training that was delivered on their smartphone as homework almost every day for 1 year. Our results could guide novel health policies for dementia prevention, in a climate of increasing concern at the governmental level regarding dementia.

Nonetheless, there are several limitations. First, our findings could not be generalized; Gangnam-gu in Seoul is one of the most economically affluent and well-developed neighborhoods in South Korea. Therefore, the level of education and the performance of elderly participants are higher than the average elderly population in Korea. Second, our study participants could not be blinded to group allocation, and the control group was not an active control. Although our intervention was mainly focused on cognitive training via smartphone applications, it also involved lifestyle modification and group cognitive training. Hence we cannot completely exclude the possibility that the cognitive benefits from this mutidisciplinary intervention cannot be exclusively attributed to the smartphone-based training. Accordingly, it would be helpful to plan a further study involving two groups that differ only in smartphone intervention. Nonetheless, in addition to self-reported questionnaires, our objective cognitive testing results support the efficacy of this intervention. Third, we could not assess sustained cognitive benefits in the participants after the cognitive interventions were completed. Therefore, further studies with long-term follow-up after intervention ends are warranted. Finally, biomarker measurement, which could support application-based cognitive training, was not possible, as this study was based on a community rather than clinic setting. Therefore, future studies are required to evaluate disease biomarkers as outcome measures.

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CONFLICTS OF INTEREST

The authors have declared no conflicts of interest for this article.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.