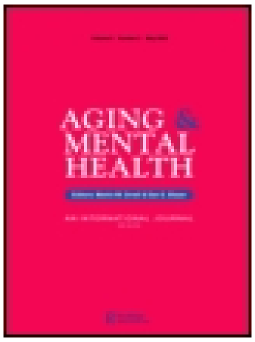

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ABSTRACT

Objectives: We explored whether newly developed application (Smartphone-based brain Anti-aging and memory Reinforcement Training, SMART) improved memory performance in older adults with subjective memory complaints (SMC).

Method: A total of 53 adults (range: 50-68 years; 52.8% female) were randomized into either one of two intervention groups [SMART ($n = 18$) vs. Fit Brains® ($n = 19$)] or a wait-list group ($n = 16$). Participants in the intervention groups underwent 15-20 minutes of training per day, five days per week for 8 weeks. We used objective cognitive measures to evaluate changes with respect to four domains: attention, memory, working memory (WM), and response inhibition. In addition, we included self-report questionnaires to assess levels of SMC, depression, and anxiety.

Results: Total WM quotient [$t(17) = 6.27$, $p < .001$] as well as auditory-verbal WM score [$t(17) = 4.45$, $p < .001$] increased significantly in the SMART group but not in the control groups. Self-reports of memory contentment, however, increased in the Fit Brains® group only [$t(18) = 2.12$, $p < .05$).

Conclusion: Use of an 8-week smartphone-based memory training program may improve WM function in older adults. However, objective improvement in performance does not necessarily lead to decreased SMC.

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Aging; cognition; memory; executive function; smartphone

Introduction

Preserved cognitive functioning is critical to healthy aging. A steadily aging population and lower mortality rates have resulted in an increase in average retirement age, and many people today are concerned about memory loss, signs of which typically occur when individuals reach their 50s (American Society on Aging and MetLife Foundation, 2006). Demand has increased for interventions targeted toward the prevention of dementia and other age-related degenerative cognitive impairments to ensure and improve quality of life in older adults, with emphasis on the maintenance of healthy cognitive functioning to promote continued overall health and participation in work/other activities of daily living. According to existing research, age-related memory loss is associated with a differential decline in executive function, which may be associated with decreased frontal lobe volume (Bartzokis et al., 2001; Cabeza & Dennis, 2013). Executive function plays a key role when an individual is required to learn new skills, solve complex problems, or perform tasks that require self-control, though such function plays a lesser role with regard to performing familiar, simple, or automatized tasks (Kim & Kim, 2015). As such, preventing age-related declines in executive function – a hallmark of higher-level thinking – appears to be crucial in maintaining a certain level of functioning for those who wish to continue healthy and active social lives.

Memory intervention for older adults with subclinical memory problem

The human brain is plastic and its development and rewiring continues into late in life (Nussbaum, 2011). In fact, various mental stimulation which the brain encounters in everyday life promotes development and maintenance of cognitive function (Hertzog, Kramer, Wilson, & Lindenberger, 2008; Lee, 2014). Therefore, prevention in the preclinical stage is likely the most effective way to decrease the incidence of age associated dreadful neurodegenerative condition, and its associated burden for individuals and society (Han & Han, 2014). Based on this understanding, various cognitive and memory enhancement programs targeting normal aging adults have garnered the interest of researchers and commercial businesses alike (Gross et al., 2012). Since the 2000s, the use of computerized cognitive training (CCT) has increased due to the relatively absence of temporal and spatial constraints (Günther, Schäfer, Holzner, & Kemmler, 2003; Miller et al., 2013). Though early programs were targeted toward rehabilitation, focus has gradually shifted to the prevention of cognitive decline.

One can expect that memory intervention targeted toward normal aging adults may be beneficial for those concerned with age-related decreases in memory function, as well as for individuals with subjective memory complaints (SMCs). SMC refers to a condition in which the patient reports decreases in

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memory function in the absence of objective impairment as indicated by the use of a standardized screening test (Schmidtke, Pohlmann, & Metternich, 2008). The prevalence of SMC is high, registering at 25%–50% (Jonker, Geerlings, & Schmand, 2000). Considering the abundant amount of research that has identified SMC as a significant predictor of future cognitive decline and dementia (Reid & MacLullich, 2006; Silva et al., 2014), prevention-based intervention is required to delay the onset of cognitive impairment and to maintain the level of performance required for normal everyday living.

Smartphone-based memory training

Devices and methods easily accessible to the average person for use in daily life have become key in the popularization of memory training, and long-term demand for non-pharmacological interventions such as memory training is expected to increase. The unprecedented spread and evolution of mobile technologies has created the burgeoning field of mHealth (mobile health) (Ryu, 2012; World Health Organization, 2011). The smartphone is one such technological tool that may serve as an external memory aid, assisting individual with memory problems through various applications ('apps') (Migo et al., 2015). According to a 2015 Korean report, 83% of national population own a smartphone, and ownership levels among adults aged 60 years and older continue to increase (Korea Gallup, 2016). It is expected that interest and demand will steadily increase for health-related apps targeted toward older adults. Although both free and paid apps designed to promote memory and cognitive function already exist in the market, unfortunately, research aimed at investigating the efficacy of standardized memory training delivered through smartphones is sorely lacking. The availability of easily accessible mobile content is increasing, supported by a growing interest in brain health and improved memory among older adults. Therefore, the demand for further evidence regarding the effects of engaging in smartphone-based memory training will continue to grow, not only by individuals with perceived memory issues but also by the clinicians who provide guidelines for maintaining brain health (Gross et al., 2012).

Although cognitive training based on new technology such as computers and smartphones has more advantages than traditional interventions, the following methodological issues should be addressed in future research so that CCT or smartphone-based cognitive training may be considered as well-established treatments. One of the most important issues is establishing an appropriate control condition. An adequate comparison condition must be matched for engagement, motivation, training time, interface (e.g. computer, smartphone), and stimuli novelty (Motter, Devanand, Doraiswamy, & Sneed, 2016). Although active controls are methodologically superior to a waitlist condition, an active control group does not ensure accounting for differential placebo effects (Simons et al., 2016). Therefore, the study design should minimize any confounding effects (e.g. placebo or expectancy). There was clear evidence of placebo effects after brief cognitive training that led to significant working memory gains (Foroughi, Monfort, Paczynski, McKnight, & Greenwood, 2016). Furthermore, controlling for practice effects is particularly important in older adults with cognitive impairment, given their propensity toward greater practice effects compared to their cognitively-stable peers (Suchy, Kraybill, & Franchow, 2011).

In the current study, we included two control groups (active controls and a waitlist group) and assessed the effects of smartphone-based cognitive training aimed at improving memory in older adults. The intervention included smartphone-based tasks that can be performed at home and thus may be more accessible to older individuals with SMC.

Methods

Participants

We recruited a total of 60 adults in their 50s and 60s who had reported SMC using advertisement posters and online bulletin boards. Inclusion criteria were as follows: (a) responses to the following two items adopted from the Subjective Memory Complaints Questionnaire (SMCQ) (Youn et al., 2009): My memory is not as good as that of someone my age and my memory has declined 10 years ago; (b) Korean-Mini Mental State Exam (K-MMSE) score of 24 points or higher (normal range) (Kwon & Park, 1989); and (c) smartphone ownership.

Exclusion criteria were as follows: (a) cognitive impairment such as Alzheimer's disease; (b) need for immediate medical attention due to potential neurocognitive impairment as suggested by the present study's screening tests for neurocognitive function; (c) and indication of untreated major depression or other major mental illness.

One participant was receiving treatment for insomnia, while three were receiving treatment for glaucoma, liver abnormalities, or gynecological disease at the time of study entry. These patients were accepted into the study because they met no other criteria for major psychiatric or neurological disorders. One candidate was excluded due to significant neurocognitive impairment as determined by the memory test (i.e. Memory Diagnostic System) at baseline. We randomly assigned the remaining participants to one of three intervention groups: the Smartphone-based brain Anti-aging and memory Reinforcement Training (SMART), Fit Brains®, and wait-list. Of the 59 participants, five withdrew from the study: One withdrew from the SMART group due to a sudden death in family, while four from the wait-list group (two refused post-training assessment, while one withdrew due to spouse's illness, and one due to travelling abroad). We excluded one participant assigned the SMART group from the analysis due to questionable accuracy upon learning that the participant was not wearing his hearing aid. Upon conclusion of the study, we analyzed the data collected from a total of 53 participants. The average age of these participants (25 men and 28 women) was 59.30 years (median age = 59 years, range = 50–68 years), with an average education level of 13.94 years (median education = 16 years, range = 6–18 years). At baseline, there were no significant differences in age, education, or with respect to any measure of cognitive performance (e.g. K-MMSE, FSIQ) among the groups (see Table 1).

The present study protocol was reviewed and approved by the institutional review board of Seoul National University Hospital (IRB No. H-1506-117-682). Informed consent was submitted by all subjects when they were enrolled.

Intervention (cognitive training)

Each training condition provided approximately 15–20 minutes of instruction per day, five days per week for 8 weeks, for a total of 40 sessions in a predetermined order. The number of

Table 1. Demographic characteristics.

Variables	SMART ($n = 18$)	Fit Brains® ($n = 19$)	Wait-list ($n = 16$)	Statistics	p-value
Age M (SD)	59.28 (5.11)	58.79 (5.00)	59.94 (5.17)	$F = 0.22$	0.802
Sex (male/female)	9/9	9/10	7/9	$\chi^2 = 0.13$	0.936
Education, years	14.22 (3.69)	14.16 (2.32)	13.38 (3.56)	$F = 0.36$	0.700
K-MMSE total	28.06 (2.04)	28.68 (1.06)	28.25 (1.57)	$F = 0.75$	0.478
FSIQ	116.78 (13.64)	114.89 (13.16)	110.25 (12.69)	$F = 1.09$	0.345
CES-D	18.44 (12.67)	14.95 (7.61)	17.69 (6.91)	$F = 0.70$	0.503
STAI-S	44.06 (14.21)	39.32 (9.36)	44.00 (7.85)	$F = 1.14$	0.328

Notes: Scores are displayed as means and standard deviations. SMART = Smartphone-based brain Anti-aging and memory Reinforcement Training; K-MMSE = Korean-Mini Mental State Exam; FSIQ = Full scale IQ on Korean-Wechsler Adult Intelligent Scale-IV; CES-D = Center for Epidemiological Studies-Depression scale; STAI-S = State-Trait Anxiety Inventory, State anxiety subscale.

sessions ('dose') is similar to that in protocols used in previous studies (Mahncke et al., 2006; Miller et al., 2013).

Toril, Reales, and Ballesteros (2014) found that training effects were better when training duration was short (1–6 weeks) than when it was long (7–12 weeks). And even though a meta-analysis of CCT in healthy older adults (Lampit, Hallock, & Valenzuela, 2014) concluded that short sessions less than 30 minutes may be ineffective, we constructed a program with shorter session length (15–20 minutes) but greater training frequency (5 days a week), because we determined that using a smartphone for more than 30 minutes in one sitting could be burdensome, given the characteristics of smartphone-based (self-administratered) training.

We handed out basic schedule sheets to the participants in the two active groups and asked them to follow this schedule. This sheet included a structured schedule that allowed the two groups to train with the same number of tasks (3) and duration (15–20 minutes) per session to conduct training as similar as possible. For instance, we asked participants to train in Level 1 during weeks 1–2, in level 2 during weeks 3–5, and in level 3 during weeks 6–8 while engaging in repeated practice at each level. We checked in with the participants for progress and conscientious participation via weekly telephone calls and text messaging. After training was completed, we checked the training records stored in the participants' smartphones with their consent to ensure that all sessions were properly completed.

Smartphone-based brain Anti-aging and memory Reinforcement Training, SMART

The newly developed smartphone application 'SMART' utilized in the present study, which targets adults over the age of 40 years, was developed to improve the user's attention and working memory, which are known to be closely associated with general memory function (Shin et al., 2015). The app offers a total of 10 training tasks. With the exclusion of the attention-shifting task and word-list task, the remaining eight tasks are tiered according to three difficulty levels, allowing the user to tackle more challenging tasks as he/she progresses. The details of task with respect to each domain are presented in Table 2 and Figure 1. Each level is designed to take an average of 5 minutes to complete. However, depending on the nature and difficulty level of the particular task, the range may fluctuate from 3 to 7 minutes. We configured a basic training schedule for all users, which allowed the users to perform three tasks (attention, memory, and working memory) per session. Results from an 8-week preliminary study conducted with 54 participants indicate that use of the app successfully improves the user's memory, working memory performance (Shin et al., 2015). The developers, however, have not yet made the app available to the public.

Fit brains®

We performed a thorough review of cognitive training apps available both in Korea and elsewhere in order to select a comparison app for the study. The selection criteria for the app were as follows: (a) If published overseas, a Korean-language version must be available; (b) tasks must be differentiated according to key cognitive domains including attention and memory; (c) tasks must be tiered according to the level of difficulty. We selected the smart phone version of Fit Brains® as the comparison app for the present study. Fit Brains® is widely known as a web- and smartphone-based cognitive training program published by Rosetta Stone®, USA (David & Gelfeld, 2014). The cognitive training domains and tasks featured in Fit Brains® are presented in Table 2, some of which are available for free at www.fitbrains.com. Fit Brains® recommends user play at least one training session (three tasks) per day. Although a previous study (Willis et al., 2006) reported that 30 sessions of Fit Brains® training resulted in improved cognitive abilities, because each task requires a fairly short time to complete (under 2 minutes on average), we asked participants to perform each task a minimum of two times in order to match the task time with that of the SMART app.

Wait-list control group

We re-evaluated the participants of the wait-list group, who were not provided with cognitive intervention, after 8 weeks, along with the participants in the training group. Following reassessment, all wait-list participants who wished to obtain the SMART application received the app.

Outcome measures

Objective cognitive function

(1) General cognition: We assessed participants' general cognition using Korean version of Mini-Mental State Exam (MMSE-K) (Kwon & Park, 1989) and Korean Wechsler Adult Intelligence Scale-IV (K-WAIS-IV) (Hwang, Kim, Park, Chey, & Hong, 2012). (2) Memory: The Memory Diagnostic System (MDS) (Shin & Kwon, 2013) is a computerized neuropsychological test battery developed to evaluate the memory function of individuals aged 40–74 years old. This battery of tests assesses various cognitive functions, including attention, verbal and visuo-spatial memory, verbal and visuo-spatial working memory, and executive function (Kim, Kwon, & Shin, 2013). Performance results are converted into scores (average score: 100; standard deviation: 15) representing each of the test domains: Attention Quotient (AQ), Memory Quotient (MQ), Working Memory Quotient (WMQ), and Executive Function Quotient (EFQ). Each detailed assessment result is converted based upon an average of 10 and standard deviation

Table 2. Skills domains and details of two smartphone-based cognitive training apps.

Intervention 1. SMART (Smartphone-based brain Anti-aging and memory Reinforcement Training)

	No.	Cognitive area	Contents
ATTENTION	1	Sustained attention	Two or more images simultaneously appear on the screen. Tap OK, as quickly as possible, if two images with identical shape and color appear on the screen.
	2	Selective attention	Find the target among the moving letters and numbers presented on the screen (numbers, Korean alphabet, English alphabet) The number of target and distracter increases as the difficulty level increases.
	3	Attention shifting and response inhibition	While remembering the different rules provided at the top of the screen (shape) and at the bottom of the screen (color), respond quickly to the target appearing on the screen.
MEMORY	4	Story memory	(1) A To do list consisting of common everyday tasks is provided (check the weather forecast) and verify their completion status the next day (Yes or No) (2) Respond to the question pertaining to the user's past, which had been pre-programmed by the user himself/herself. (3) A short paragraph containing trivia is presented, followed by a problem. The type of problem changes according to difficulty level (OX quiz, multiple choices, short answers).
	5	Word list	A list of 12 words is presented (three categories, ex: sports, body parts, office supplies), 4 immediate recall and 1 recognition tasks are performed.
	6	Memory interference	Two word lists are presented in sequence. The user is asked to recall only the words in the first or second list according to the command.
	7	Visual-spatial memory	Target object is presented and then breaks into puzzle pieces, which are then scattered across the screen and shielded. The user is asked to reconstruct the object by recalling the original shape and locations of the puzzle pieces.
WORKING MEMORY	8	Selective processing	Memorize numbers in presented in a predetermined sequence. When the board is removed, re-enter the numbers in the right order. Here, 1 is added to the numbers, which had been presented in the color red.
	9	Calculation	Perform addition and subtraction while following the rules suggested on the screen and tap the balloons containing the answers (e.g. +5 rule: 7→12→17→22…)
	10	Visual-spatial WM	Board 1 and 2 containing shapes sequentially appear in predetermined locations on the grid. The user selects the grid(s) where the two shapes overlap.

Intervention 2. Fit Brains®

Cognitive area	No.	Title	Contents
FOCUS (concentration)	1	Matching pairs	Further information of these tasks are available at www.fitbrains.com
	2	Paint drops	
SPEED	3	Speed sort	
	4	Quick blocks	
MEMORY	5	Missing pieces	
	6	Spot the difference	
VISUAL	7	Stacked discs	
	8	Shadow shapes	
LOGIC (problem solving)	9	Perfect patterns	
	10	Coin calc	

of 3 (however, the attention score is converted into a T-score.) (3) The executive function tests: We used the Korean-language version of the Stroop Color and Word Test (SCWT) (Seo et al., 2008) to assess the participants' inhibitory processing, the key functions of the frontal lobe.

Self-report questionnaires

(1) Center for Epidemiologic Study-Depression (CES-D) (Chon, Choi, & Yang, 2001): We asked participants to fill out a 20-item questionnaire based on the frequency of depressive symptoms they experienced during the previous week. According to a Korean study (Cho & Kim, 1993), the optimal cut-off score is 25 points. (2) State-Trait Anxiety Inventory (STAI) (Hahn, Lee, & Chon, 1996; Spielberger, 1983): For the present study, we used only the state anxiety subscale. According to a Korean study (Hahn et al., 1996), the average state anxiety score among male adults over the age of 30 years was 40.91 points ($SD = 9.84$), while that of their female counterparts was 42.20 points ($SD = 9.06$). (3) Multifactorial Memory Questionnaire (MMQ) (Chin, 2011; Troyer & Rich, 2002): The MMQ includes the following three subscales: (a) MMQ-C (Contentment), which assesses the respondent's contentment with his/her memory; (b) MMQ-A (Ability), which assesses the frequency of memory-related problems experienced in daily life; and (c) MMQ-S (Strategy), which assesses the frequency of use of compensatory strategies for memory problems. The MMQ was originally developed as a 5-point scale. However, a previous study reported difficulties in rating the MMQ when administered to a group of elderly Korean participants. For this reason, we used a modified version (Chin, 2011) rated along a 3-point scale in the present study (0 = I do not agree, 1 = I agree, 2 = I strongly agree). Higher scores indicated greater satisfaction with one's memory, fewer memory problems, and more frequent use of compensatory strategies.

Statistical analyses

We compared the baseline cognitive scores and self-report questionnaire scores of participants who withdrew prior to study completion with those of participants who completed the study using a Mann-Whitney U-test for independent samples. In order to examine group differences in terms of age, education (years), IQ, depression score, and anxiety score, we performed a multivariate analysis of variance (MANOVA). Additionally, we performed a 3 × 2 repeated measures MANCOVA [Group (SMART vs. Fit Brains® vs. wait-list) × Time (baseline and retesting)] in order to examine the significance of group differences with respect to changes in neurocognitive assessment results and self-report questionnaire (MMQ) scores before and after the training. Group differences in baseline IQ scores and depression symptoms were not significant, though the scores of the SMART group were relatively

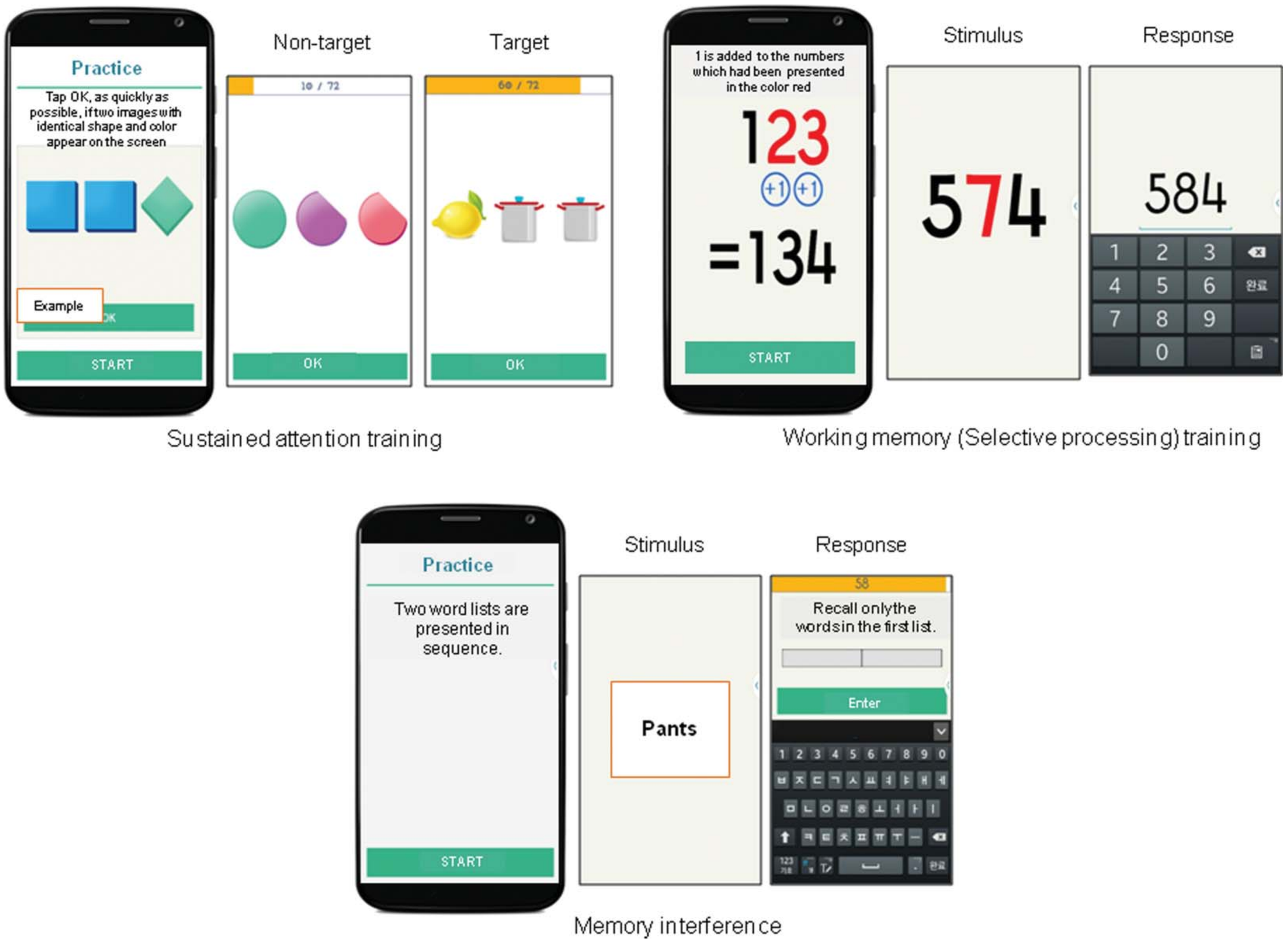

Figure 1. The SMART (Smartphone-based brain Anti-aging and memory Reinforcement Training). Each screen shows the instructions, the stimulus presentations, and the response phases of the tasks.

high. Therefore, we set baseline IQ and changes in CES-D score as covariates and evaluated the specific effects of the training using *post hoc* analyses for significant interactions only. Specifically, we performed paired *t*-tests for each group in order to evaluate pre- and post-training differences in scores. We used IBM SPSS Statistics Version 18 (Chicago, IL) for all statistical analyses.

Results

The five participants who withdrew from the study had lower Working Memory Quotient (WMQ) on the MDS than the 48 who completed the study (90.84 vs. 106.58; Mann-Whitney's *U*-test, $p < .01$). Differences in other MDS sub-scores, MMSE-K, IQ, and self-report questionnaire scores were not significant.

Neurocognitive performance

Changes in scores and levels of statistical significance for each group are presented in Table 3. Analysis revealed significant time by group interaction effects for WMQ and auditory-verbal working memory (WM) score, indicating significant improvement after controlling for IQ and changes in depressive symptoms. Further analysis revealed a significant main effect of time alone in the cases of Trail Making Test A and B as well as EFQ of MDS. With regard to the assessment of executive function, we observed no interaction on the Stroop test. Table 4 presents the results of the *post hoc* paired *t*-test between pre- and post-training outcomes that showed significant interactions in MANCOVA. Increases in WMQ and auditory-verbal WM were significant only in the SMART group.

Self-report questionnaires (SMC and mood)

We observed a significant group-by-time effect for MMQ-C scores, which reflect one's overall satisfaction with the current memory function (Table 3). Results of a *post hoc* paired *t*-test indicated a post-training MMQ-C score increase in the Fit Brains® group only (Table 4). Analysis revealed a significant main effect of time for CES-D and STAI-S scores yet no group-by-time effect, indicating that levels of depression and anxiety decreased between baseline and reassessment for participants in the memory intervention groups as well as for those in the wait-list group.

Discussion

In our technological society, computer-based training programs have attracted researchers' attention as possible tools for improving and/or maintaining perceptual and cognitive functions in older adults (Ballesteros, Kraft, Santana, & Tziraki, 2015). However, existing scientific evidence of the potential of CCT and smartphone-based training is mixed.

The present study examined the effects of an 8-week smartphone-based memory training program on normal aging older adults with SMC. The results indicated that group-by-time interaction was significant only in terms of WM among the objective performance measures. The observed enhancement in

Table 3. Comparisons between the groups on outcome measures.

		Intervention 1 SMART ($n = 18$)		Intervention 2 Fit Brains® ($n = 19$)		Waiting ($n = 16$)				
		Pre *M* (SD)	Post *M* (SD)	Pre M (SD)	Post *M* (SD)	Pre *M* (SD)	Post (SD)	*F* (Time)	*F* (Group)	*F* (T×G)
MDS	Attention Quotient: AQ	98.62 (4.34)	98.54 (6.35)	98.88 (5.45)	98.88 (7.81)	99.32 (4.45)	99.49 (6.63)	0.01	0.25	0.01
	Memory Quotient: MQ	104.16 (9.06)	110.13 (12.86)	107.35 (12.62)	110.34 (9.17)	103.66 (14.27)	110.44 (15.26)	0.15	0.60	1.48
	Working Memory Quotient: WMQ	107.43 (9.75)	116.22 (9.66)	109.19 (14.06)	112.12 (11.56)	102.53 (10.86)	104.04 (12.15)	0.64	2.19	3.83*
	Executive Function Quotient: EFQ	105.39 (11.67)	108.69 (7.14)	111.03 (6.87)	112.10 (6.24)	106.40 (8.73)	108.11 (6.85)	18.23***	2.64	1.22
: Attention	Omission error†	50.98 (7.09)	51.43 (9.27)	50.88 (7.48)	48.53 (12.01)	52.36 (9.72)	51.14 (8.11)	0.04	0.48	0.43
	Commission error†	54.96 (5.24)	56.26 (4.64)	52.38 (7.15)	53.93 (6.62)	55.84 (5.07)	57.96 (2.50)	0.55	4.44*	0.05
	Reaction time†	40.40 (8.10)	39.39 (8.78)	43.49 (10.43)	44.75 (12.48)	39.20 (11.37)	40.80 (11.02)	0.60	0.88	0.70
	Reaction time SD†	49.99 (5.75)	48.99 (6.65)	50.10 (4.89)	49.79 (5.57)	50.79 (5.28)	48.74 (7.21)	0.31	0.03	0.36
: Memory	Auditory-Verbal immediate	10.80 (2.59)	11.73 (3.30)	11.76 (3.42)	12.22 (2.77)	11.16 (3.66)	12.51 (4.23)	0.82	0.83	0.45
	Auditory-Verbal delayed	10.64 (3.07)	11.47 (3.24)	11.11 (2.84)	12.40 (3.15)	10.76 (3.16)	12.36 (3.26)	0.15	0.89	0.52
	Visual-Spatial immediate	10.93 (2.57)	13.04 (3.89)	12.22 (3.46)	12.55 (2.66)	10.96 (3.11)	12.29 (3.76)	0.52	0.42	1.63
	Visual-Spatial delayed	11.08 (2.98)	12.78 (3.36)	12.05 (3.64)	12.44 (2.90)	10.50 (3.87)	11.96 (3.81)	0.90	0.38	1.75
WM	Auditory-Verbal WM	11.24 (2.99)	13.74 (2.66)	11.59 (3.91)	12.26 3.56)	10.15 (2.90)	10.54 (2.84)	4.48*	1.24	4.49*
	Visual-Spatial WM	11.74 (2.58)	13.10 (2.46)	12.08 (2.25)	12.58 (2.48)	10.86 (2.77)	11.08 (2.52)	0.16	1.53	0.81
TMT	Set-A	10.84 (2.46)	11.29 (2.36)	11.93 1.69)	12.06 (2.01)	11.41 1.86)	11.79 1.58)	8.21**	1.54	0.25
	Set-B	11.32 (2.54)	12.18 (0.95)	12.48 (1.80)	12.78 (1.25)	11.15 (2.37)	11.46 (2.03)	11.39**	2.84	1.36
SCWT	Stroop: word‡	84.17 (11.04)	91.06 (10.02)	88.32 (11.19)	93.16 (7.80)	79.13 (13.39)	82.38 (12.30)	0.18	3.68*	0.58
	Stroop: color‡	69.61 (9.41)	72.89 (12.16)	72.11 (10.57)	73.32 (9.25)	64.19 (7.87)	68.50 (9.47)	0.01	1.58	0.94
	Stroop: color-word‡	43.00 (8.05)	46.00 (8.68)	45.26 (9.10)	46.53 (10.82)	36.81 (8.66)	42.38 (9.42)	0.03	1.79	3.03
MMQ	Contentment (max = 36)	21.39 (6.27)	20.39 (7.21)	17.16 (7.99)	20.16 (6.83)	20.63 (8.62)	19.75 (7.22)	0.11	0.61	3.86*
	Ability (max = 40)	22.89 (6.89)	24.50 (5.89)	22.21 (7.71)	24.11 (6.55)	24.69 (6.70)	24.38 (9.65)	0.13	0.49	1.20
	Strategy (max = 38)	19.44 (7.25)	19.39 (7.34)	17.32 (5.80)	19.11 (5.48)	16.13 (7.50)	18.81 (9.66)	1.73	0.21	0.43
Mood	CES-D	18.44 (12.67)	14.89 (11.03)	14.95 (7.61)	13.58 (8.55)	17.69 (6.91)	15.50 (9.61)	10.96**	0.40	0.83
	STAI-S	44.06 (14.21)	39.67 (10.78)	39.32 (9.36)	38.37 (6.84)	44.00 (7.85)	41.69 (10.87)	5.44*	0.87	0.88

Note: SMART = Smartphone-based brain Anti-aging and memory Reinforcement Training; MDS = Memory Diagnostic System; AQ = Attention Quotient; MQ = Memory Quotient; WMQ = Working Memory Quotient; EFQ = Executive Function Quotient; WM = working memory; TMT = trail making test; MMQ = Multifactorial Memory Questionnaire; SCWT = The Stroop Color and Word Test; MMQ = Multifactorial Memory Questionnaire; CES-D = Center for Epidemiological Study-Depression; STAI-S = State-Trait Anxiety Inventory, State anxiety subscale.
*$p < .05$; **$p < .01$; ***$p < .001$; †*T*-score; ‡raw score.

WM as a result of memory training in the present study is consistent with the results of previous studies that have reported cognitive plasticity even for older adults. Although not all outcome measures reflected improved cognitive function, the significant increase in WM is noteworthy. This is because, unlike in Alzheimer's disease – a condition characterized by pathological changes in the temporal or parietal lobes – SMC in healthy aging adults is highly suspected to reflect declining working memory, which is dependent on the executive functioning capabilities of the frontal lobe (Ryu et al., 2007).

The fact that WM only improved in the SMART group could be due to differential process training. Although both SMART and Fit Brains® are multi-domain cognitive training programs, the SMART group trained memory (four tasks) and WM (three tasks) more than the Fit Brains® group (just two memory tasks). Differential process training could result in variable neurocognitive performance. Furthermore, SMART also included three attention tasks including selective and sustained attention and response inhibition training, so there is a possibility that SMART training led to greater improvements on the WM tests. WM performance is closely linked to other executive-control functions, including selective attention and inhibitory control (Kane & Engle, 2003), sustained attention (Holmes et al., 2014), and nonverbal reasoning (Kane et al., 2004). In addition, a meta-analysis of CCTs (Lampit et al., 2014) reported that among the cognitive domains including processing speed, verbal/non-verbal memory, attention, and WM, only the last domain showed statistically significant improvements even under such conditions as home-based training, a relatively small dose (20 hours or less), and short session length (30 minutes or less). In other words, WM can be improved even by using a shorter cognitive training compared to other domains, and a long-term intensive training protocol is needed to achieve general memory improvements. Recent research (Toril, Reales, Mayas, & Ballesteros, 2016) reported that training older adults with 15 one-hour video game training sessions enhanced visuospatial WM and episodic memory in the trained group.

WM is a key component of cognition that deteriorates greatly with age (Ballesteros et al., 2015). Existing research has

Table 4. *Post hoc* comparison (paired *t*-test) in outcomes showing significant group × time interaction.

			Change mean (Δ = post – pre) *M* (SD)	95% confidence interval	*t*	*p*-value
MDS	WMQ	SMART	8.78 (5.94)	5.83–11.74	6.27	<.0001
		Fit Brains®	2.93 (10.30)	−2.03–7.90	1.24	0.231
		Wait-list	1.52 (6.09)	1.73–4.76	1.00	0.334
	Auditory-Verbal WM	SMART	2.51 (2.39)	1.32–3.69	4.45	<.0001
		Fit Brains®	0.67 (2.80)	−0.68–2.02	1.04	0.311
		Wait-list	0.39 (2.08)	−0.72–1.50	0.75	0.467
MMQ	MMQ-C (Contentment)	SMART	−1.00 (3.24)	−2.61–0.61	−1.31	0.207
		Fit Brains®	3.00 (6.16)	0.33–5.97	2.12	0.048
		Wait-list	-0.88 (4.44)	−3.24–1.49	−0.79	0.443

Note: SMART = Smartphone-based brain Anti-aging and memory Reinforcement Training; MDS = Memory Diagnostic System; WMQ = working memory quotient; WM = working memory; MMQ = Multifactorial Memory Questionnaire.

revealed that age-related increases in neural activity are prominent in the prefrontal cortex (PFC), suggesting that compensatory changes may be more active in shaping the function of the PFC, which controls various cognitive functions including working memory, reasoning, and impulse control/inhibition (Cabeza & Dennis, 2013).

An intervention aimed at improving cognitive abilities could be useful depending on the extent of improvement for abilities not directly trained during the intervention (Ballesteros et al., 2015). However, evidence for the effective transfer of cognitive training to untrained tasks is mixed (Tidwell, Dougherty, Chrabaszcz, Thomas, & Mendoza, 2014), and recent meta-analyses of WM training (Karbach & Verhaeghen, 2014; Melby-Lervåg, Redick, & Hulme, 2016) reported that far transfer effects (e.g. improvements on every day or 'real-world' functioning) were smaller than near transfer effects (e.g. improvements on one WM task after training on another WM task), especially in older adults (Karbach & Verhaeghen, 2014).

Despite SMC, participants in the present study exhibited above-average performance on memory assessments. Even after taking into account that a high level of educational attainment is a risk factor for SMC (Schofield et al., 1997), the study participants had an average IQ of 114.13 (SD = 13.21). Furthermore, 60.4% ($n = 32$) reported having attained an associate's or bachelor's degree (a minimum of 13 years of education) [elementary school degree or less: 7.5% ($n = 4$); middle school or high school degree: 32.1% ($n = 17$)], with a large proportion reporting above average cognitive performance. A previous study (Kwok, Bai, Li, Ho, & Lee, 2013) has reported that group cognitive training was effective in enhancing the overall cognitive functioning of less-educated older adults with SMC, and that the practice effect was more evident for the most educated participants.

In the present study, participants in the Fit Brains® group reported an increased overall satisfaction with memory post-training, while the participants in the SMART group with significant improvements in WM did not report improved satisfaction. These results suggest that objective improvement in performance does not necessarily lead to decreased SMC. The motivational component of training is particularly important in the case of older participants (Hertzog et al., 2008). With Fit Brains®, users must achieve the current level's target score before moving on to the next level. We suspect that the users' self-efficacy and sense of achievement grew as they progressed toward the end of the program while successfully completing tasks presented in order of increasing difficulty. On the other hand, some of the tasks in the SMART program are not tiered according to difficulty level, and they are designed in a way that allows the user to access more challenging tasks regardless of his/her current performance level, which may have delivered less intense internal reward and motivation to excel, even if the user could successfully conquer the training goals. With regard to compensatory strategies used by participants as measured by the MMQ-S, we observed no post-training improvement in either of the intervention groups. We suspect this to be due to the lack of training protocol contents encouraging the use of such strategies. Several studies reported that intervention pertaining to 'expectancy change' (e.g. cognitive restructuring and psychoeducation) (Metternich, Kosch, Kriston, Härter, & Hüll, 2008) or meta-memory concept (Youn, Lee, Kim, & Ryu, 2011) were efficient at reducing SMC.

Study limitations and implications

The present study has some limitations. First, the participant sample poses an issue. Although the participants consisted of individuals with SMC, they had never received medical attention for the condition. Furthermore, their education level, baseline IQ, and memory performance were measured at +1 SD point on average, which limits generalization of the study results across all older adults with SMC. Because the small number of participants per condition could reduce statistical power, future studies should employ larger sample sizes. Another limitation is that we were unable to control individual participant environment during the eight-week training period, making it difficult to confirm just how conscientiously the participants engaged in the training regimen. In this vein, despite its convenience and high accessibility, smartphone-based memory training poses a disadvantage in terms of ensuring a consistent training environment for all participants, as it tends to be greatly affected by individual circumstances and motivation. We chose an active control that matches the conditions of interface, novelty, etc., to solve the potential problem associated with expectancy, but all participants were informed of the study goal and group assignments when they agreed to participate. This may have acted as a confounding factor (e.g. implicit belief in the outcome or outcome expectancy). Assessing expectancy and personal belief of cognition malleability before randomization to ensure adequate representation in all groups could allow us to better assess the true training effects (Foroughi et al., 2016). Finally, we did not examine how long the effects can be maintained. The ultimate goal of memory training is improved daily function. Therefore, a long-term follow up assessment using outcome measures to examine whether training effects indeed transfer to everyday life would be beneficial.

Despite these limitations, the present study contributes to the existing body of knowledge in the following ways. To our knowledge, it is the first control group study to verify the effects of smartphone-based memory intervention on normal aging older adults with SMC. The findings of the present study provide evidence pertaining to new memory training methods for clinicians and older adults preparing for their golden years.

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