Effect of a Computerized Brain Exercise Program on Cognitive Performance in Older Adults

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Objectives: *Research indicates an association between stimulating mental activities and better memory performance as people age, but studies on computerized mental stimulation programs are limited. We explored whether computerized brain training exercises improved cognitive performance in older adults.* **Methods:** *In local retirement communities, a convenience sample was randomized into an intervention group (N = 36), who used a computer program 5 days a week for 20–25 minutes each day, or a wait-list control group (N = 33). All were older adults without dementia (mean age: 81.8 years; SD: 6.1; 67% female). Neuropsychological testing was completed at baseline (Time 1), 2 months (Time 2), and 6 months (Time 3). Three cognitive domains (Immediate Memory, Delayed Memory, Language) were compared in the two groups as a function of time using mixed models.* **Results:** *The intervention group used the computerized program (Brain Fitness, Dakim Inc., Santa Monica, CA) for an average of 43 (SD: 4.4) sessions by Time 2 and 81 (SD: 37.5) sessions by Time 3. Mixed models examining cognitive domains as function of time revealed significant group differences in Delayed Memory (F(2,72) = 4.7, p = 0.01) but not Immediate Memory and Language; no significant improvements were noted for the control group. Among all participants, anyone playing at least 40 sessions over the 6 months improved in all three domains (Immediate Memory, Delayed Memory, and Language).* **Conclusion:** *Participating in a computerized brain exercise program over 6 months improves cognitive abilities in older adults. These results extend literature indicating the benefit of training exercises, whether in a classroom format or via a computerized self-paced program.* (Am J Geriatr Psychiatry 2013; 21:655–663)

Key Words: Cognitive training, older adults, memory

Cognitive change is a common characteristic of normal aging.[1] Steady declines in memory, processing speed, and reasoning have been found to occur as early as ages 20–30 years in healthy, educated adults.[1] These mild declines, referred to as age-associated memory impairment, are characterized

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by intact performance on objective testing compared with age-related peers.[2] Given that increasing age represents a risk for dementia,[3] the possible progression of age-associated memory impairment to dementia has been of particular concern among older adults.[2,4] Although only 1%–2% of older adults progress from age-associated memory impairment to dementia within a 1-year time span,[5] the rate of progression increases substantially over a 3- to 4-year period, with anywhere from 9% to 50% converting from normal aging to dementia.[6,7]

One factor that may buffer the progression of age-associated memory impairment to dementia is *cognitive reserve*,[8,9] which refers to the capacity to cope with normal and disease-related changes in the brain associated with aging.[9,10] Individuals with high cognitive reserve can function for a relatively longer time than those with low reserve without demonstrating clinical impairment.[10] Factors believed to contribute to reserve include mentally stimulating activities, such as education, occupational attainment, and leisure time activities.[10,11] Prospective observational studies have found an inverse relationship between frequency in mental activity and cognitive decline[12] and decreased risk for dementia.[13,14]

Few randomized control studies, however, have examined mental activity as an intervention. In fact, a systematic literature review of cognitive intervention studies among individuals with mild cognitive impairment suggested that these interventions were found to be more effective on measures of mood and quality of life than on objective measures of memory and other cognitive domains.[15] To date, the largest randomized clinical trial is the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study, which recruited 2,802 healthy elderly individuals, ages 65–94.[16] The ACTIVE trial examined the efficacy and durability of cognitive interventions in improving performance on basic measures of cognition.[16] Three distinct cognitive interventions—1) verbal episodic memory, 2) reasoning and problem solving, and 3) processing speed— were allocated into ten 60-minute training sessions over the course of 6 weeks. Results demonstrated that each of these training interventions led to domain-specific improvements on basic cognitive measures.[16] Additionally, these same domain-specific improvements remained evident 5 years after the intervention.[17] Another study examined the effect of cognitive training on memory among a sample of depressed elderly participants ($N = 41$). Results demonstrated that individuals who had received 10 weeks of memory training showed better visual memory and better verbal memory retention compared with the control group, suggesting that cognitive training does appear to improve memory.[18]

A more flexible and cost-effective approach to cognitive interventions may include computer programs, which can be performed in the home and thus may be more easily accessible to older adults. For example, the Improvement in Memory with Plasticity-base Adaptive Cognitive Training (IMPACT) study enrolled older adults (ages 65 and older) into a randomized, computerized cognitive training program (intervention) versus a general cognitive stimulation group (active control); over an 8-week period, improved memory and attention after 40 hours of training was noted.[19] Other studies demonstrated improvements in learning efficiency,[20] attention,[4] and overall cognitive performance[21] after completing a computerized memory program; most studies included a wait-list control group, with the exception of one that included an active control group who watched DVDs on art, history, or literature.[19] The duration of the intervention was typically 6 weeks to 3 months in those studies.[4,19,21]

In the current study, we include a control group and assess the efficacy of a computerized brain fitness program aimed at improving memory in older adults. Based on previous studies[4,19,21] and our recent experience conducting a classroom-based memory training study for 6 weeks,[22] we decided to conduct the intervention for 2 months. We also include a longer follow-up at 6 months to examine the possible benefits of continued participation in the intervention.

METHODS

A total of 133 subjects were recruited and screened at local retirement communities in southern California. Thirty-two individuals declined to participate or did not meet the study inclusion criteria (i.e., cognitive screening indicated a diagnoses of dementia) based on one or more of the baseline measures (Mini-Mental State Examination < 24, Montreal Cognitive Assessment < 17; −1.5 standard deviation [SD] on delayed recall for Hopkins Verbal Learning

Test-Revised). After baseline clinical assessments, 101 subjects were administered full neuropsychological evaluations. Of these individuals, 17 met criteria for dementia (based on comprehensive neuropsychological testing) or reported significant health problems that impeded them from participating (i.e., recent stroke, surgery, etc.) and were not included in the study. As a result, 84 subjects were randomized: 42 to the intervention group (i.e., using the computer program, *Brain Fitness*; Dakim Inc.) and 42 to the control group.

Before the 2-month evaluation, 10 subjects (6 from the control group and 4 from the intervention group) dropped out, with most reporting as reasons lost interest in participating in the study, travel plans, and health problems. Thus, 74 subjects (38 in the intervention group and 36 in the control group) completed the comprehensive neuropsychological testing at Time 2.

Before the final assessment at the 6-month time point, three additional subjects from the control arm and two subjects from the intervention arm dropped out of the study. Again, similar reasons for dropping out were reported: no longer interested in participating in the study, travel plans, and health problems. Hence, 69 subjects (36 in the intervention arm and 33 in the control arm) completed the study (Fig. 1).

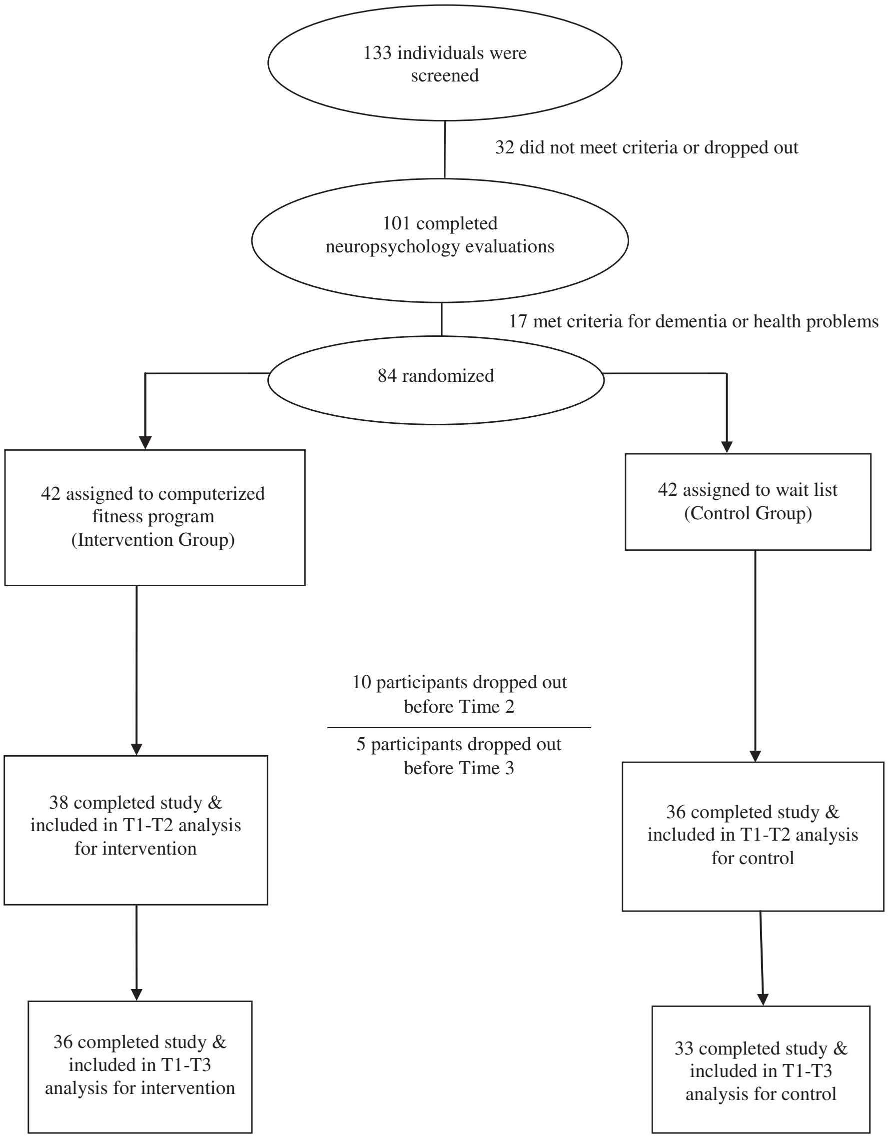
Subjects who withdrew from the study did not differ significantly from those who completed the study in demographic or baseline cognitive measures. Of the subjects that did withdraw, the most common reasons were extensive travel plans (i.e., would be away from the site for 3 weeks or more), disinterest in participating in additional neuropsychological evaluations (i.e., believed the testing process was stressful, cumbersome, or took too much time), or health-related concerns (i.e., difficulty recovering from the flu or an unexpected surgery).

Participants in the intervention group were asked to use the computer program at least 5 days a week for 20–25 minutes each day for 8 weeks (with the goal of completing 40 sessions within a 2-month time period), whereas those in the control group were placed on a waiting list and instructed not to engage in any type of cognitive training for the initial 2-month period of the study. Although the control group was not monitored, per se, at the Time 2 evaluation, the neuropsychological examiner asked the participant if he or she had engaged in any type of specific memory training during the 2-month wait periods; no one had. After 2 months, access to the computer program was offered to both groups, and participants were encouraged to engage in as few or as many computer training sessions as they wanted for the next 4 months.

The participants played Dakim's *Brain Fitness*, a structured, computerized brain-training program, which trains individuals with more than 400 exercises in six cognitive domains (short-term and long-term memory, language, visual spatial processing, reasoning/problem solving, and calculation skills) in 20- to 25-minute sessions (6–10 exercises per session). The content is delivered in a set based on algorithms that ensure an even balance among domains and an appropriate level of challenge, which continuously adjusts across five levels of activity, depending on how the participant is performing that session. Although all players receive comparable training, with equal emphasis among the domains listed above, the exact sequence of exercises depends on the player's level of ability. Thus, there is no predetermined sequence of the exercises presented in each session. The typical format includes a warm-up exercise (language task), then an immediate memory task (i.e., learn these names/faces, list of words, etc.), followed by additional nonmemory tasks from the other cognitive domains, concluding with a short-term memory recall task (i.e., recalling the names/faces or list of words from earlier in the session). The memory exercises incorporated the teachings of common memory training techniques, including visualization, association, the story method, and face–name association.[23,24]

Neuropsychological testing was completed at baseline (Time 1), after 2 months (Time 2), and after 6 months (Time 3) and included objective memory measures (Verbal Pairs Subtest from the Wechsler Memory Scale—Third Edition; Buschke-Fuld Selective Reminding Test; and Rey-Osterrieth Complex Figure Test) and language measures (COWAT–Verbal Fluency and Boston Naming Test). These two cognitive domains were assessed because of research indicating that declines in memory and language predict the greatest risk for conversion to Alzheimer disease among a sample of individuals with mild cognitive impairment.[25] Additionally, all participants completed a measure of mood at each time point (Geriatric

FIGURE 1. Study flowchart.



Depression Scale [GDS]).[26] Number of computer game sessions played by each participant was recorded at the 2- and 6-month time points.

Data Analysis

Demographic variables (age, sex, education, and ethnicity) and neuropsychological test scores at baseline of the intervention and control groups were compared using χ^2 statistics for the categorical measures and t tests for the continuous measures. To evaluate the effects of the intervention, three cognitive domains, namely Immediate Memory (Total Buschke-Fuld, Copy Rey-Osterrieth, and Total Learning VPA I), Delayed Memory (Delayed Buschke-Fuld, Delayed Rey-Osterrieth, and Delayed Recall VPA II), and Language (Boston Naming, Animals) were assessed. Z scores of the tests in each domain were averaged to yield a domain score, and these domain scores were used as the outcome measures for cognition.

TABLE 1. Baseline Characteristics of Subjects

	Intervention Group (N = 38)	Control Group (N = 36)
Age, y, mean (SD)	82.2 (4.4)	81.5 (7.6)
Education, y, mean (SD)	16.2 (2.2)	15.9 (2.1)
Sex, female, no. (%)	27 (71)	23 (64)
Ethnicity, white, no. (%)	35 (92)	36 (100)
Mini-Mental State Examination, mean (SD)	28.0 (1.5)	27.9 (1.7)
Montreal Cognitive Assessment, mean (SD)	24.2 (3.1)	24.3 (3.0)
Wechsler Test of Adult Reading, standard score, mean (SD)	113.1 (8.3)	113.7 (9.2)

GDS scores were used to compare mood changes in the intervention and control groups. We estimated general linear mixed models (as implemented in SAS PROC MIXED [SAS Institute Inc., Cary, NC]), with the cognitive domain or GDS scores as the dependent variables, group (intervention versus control), time (Time 1, Time 2, and Time 3), and a group by time interaction term as predictors. Four mixed models were estimated, one for each cognitive domain and one for GDS. The general linear mixed model permits analysis of the time course (from baseline to the 2-month assessment to the 6-month assessment) of the functioning of the two groups in a single estimation, even when some subjects dropped out between Time 2 and Time 3. If the group by time interaction term was significant, post-hoc analyses were conducted to determine whether participants improved from baseline (Time 1) to the 2-month assessment (Time 2) as well as to the 6-month assessment (Time 3). Effect sizes (Cohen's d) for the changes (Time 2 − Time 1 and Time 3 − Time 1) were calculated for both groups.

To determine whether there was a dose effect, we conducted regression analyses examining the relationship of the improvement in cognitive domain scores and number of session played both for the two groups combined and within each group. A visual inspection of the distribution of the number of sessions revealed that the intervention group played a minimum of 40 sessions during the 6-month period of the study and the control group's median number of sessions was 40. We thus also decided to examine whether participants who had played at least 40 sessions improved significantly compared with those who had played less than 40 sessions using t tests. A significance level of 0.05 was used for all the primary inferences, and Tukey-Kramer adjustment was applied for the post-hoc analyses.

RESULTS

The intervention and control groups did not differ in any of the baseline demographic measures, namely, age, prior educational achievement, sex, and ethnicity (Table 1). Treatment groups also did not differ according to Mini-Mental State Examination, Montreal Cognitive Assessment, GDS, or any of the neuropsychological test scores at baseline. The intervention group used the computerized program for an average of 43 sessions (SD: 4.4; range: 38−59) during the initial 2-month period; during the "free play" period (between Time 2 and Time 3 evaluations), they played an average of an additional 38 sessions (SD: 34.3; range: 0−120), resulting in an average of 81 sessions (SD: 37.5; range: 40−179) during the entire 6-month period. In comparison, the control group played on average 49 sessions (SD: 35.7; range: 2−126) during the final 4-month period of the study.

Table 2 presents the cognitive test scores of the two groups at baseline, 2-month assessment, and 6-month assessment. Of the three cognitive domains assessed, we found significant between-group differences only in Delayed Memory (group by time interaction term: $F(2,72) = 4.7$, $p = 0.01$). Compared with Time 1, the intervention group had significantly better Delayed Memory at Time 2 ($t(72) = 3.4$, Tukey-Kramer adjusted $p = 0.01$) and at Time 3 ($t(72) = 7.2$, Tukey-Kramer adjusted $p \leq 0.001$; see Fig. 2). Subjects in the control group did not show any change in performance from baseline to Time 2 ($t(72) = 1.8$, Tukey-Kramer adjusted $p = 0.5$), and their improvement failed to reach significance at Time 3 ($t(72) = 2.8$, Tukey-Kramer adjusted $p = 0.07$). The effect sizes for the intervention group from Time 1 to Time 2 and from Time 1 to Time 3 were 0.33 and 0.67, respectively, for the Delayed Memory domain scores, whereas the corresponding effect size for the control group was 0.20 and 0.25. There were no significant between-group differences in the change in GDS scores.

Regression models using number of sessions as a continuous measure did not yield a significant association between improvement in cognitive scores and number of sessions played. However, of the 69 subjects who completed the study, participants who

TABLE 2. Neuropsychological Test Scores of Subjects

	Intervention Group			Control, Mean (SD)		
Domain[a]/Test	Time 1	Time 2	Time 3	Time 1	Time 2	Time 3
Delayed Memory[b]						
Delayed Buschke-Fuld	6.89 (3.19)	7.03 (3.54)	8.11 (3.24)	7.34 (2.83)	7.17 (3.35)	7.72 (3.36)
Delayed Rey-Osterrieth	13.83 (5.92)	14.75 (5.98)	16.15 (6.43)	15.00 (6.14)	16.76 (6.58)	16.32 (7.26)
Delayed VP	4.79 (2.67)	6.00 (2.29)	6.58 (1.96)	5.86 (2.33)	6.44 (2.05)	6.33 (2.15)
Immediate Memory						
Buschke-Fuld Total	90.21 (17.59)	92.41 (17.20)	95.60 (19.42)	85.50 (20.32)	91.69 (20.74)	92.91 (20.14)
Rey-Osterrieth Copy	29.76 (3.77)	28.76 (4.95)	29.24 (4.06)	29.07 (5.31)	28.29 (5.31)	27.27 (6.21)
VP Total	15.76 (8.35)	19.68 (7.82)	22.11 (7.61)	18.33 (8.66)	21.14 (7.70)	21.36 (7.80)
Language						
FAS	37.50 (10.39)	40.05 (10.00)	41.03 (10.52)	40.67 (9.60)	40.08 (10.27)	42.24 (11.07)
Animal Naming	18.47 (4.57)	19.29 (5.09)	19.72 (4.90)	19.25 (3.73)	20.08 (5.17)	19.30 (4.13)
Boston Naming Test	54.87 (3.21)	56.37 (2.75)	56.94 (2.43)	55.75 (4.99)	56.47 (5.27)	56.67 (5.13)

Notes: Values are means, with SDs in parentheses. ES: effect size; FAS: Verbal Fluency Task; VP: Verbal Pairs subtest of the Wechsler Memory Scale, Third Edition.

[a] Domain scores are constructed by averaging the Z scores of the tests belonging to that domain.

[b] F(2,72) = 4.7, p = 0.01; intervention group: ES(Time 2 − Time 1) = 0.33; ES(Time 3 − Time 1) = 0.67; control group: ES(Time 2 − Time 1) = 0.20; ES(Time 3 − Time 1) = 0.25.

FIGURE 2. Delayed memory Z scores for intervention and control groups from Time 1 to Time 3.

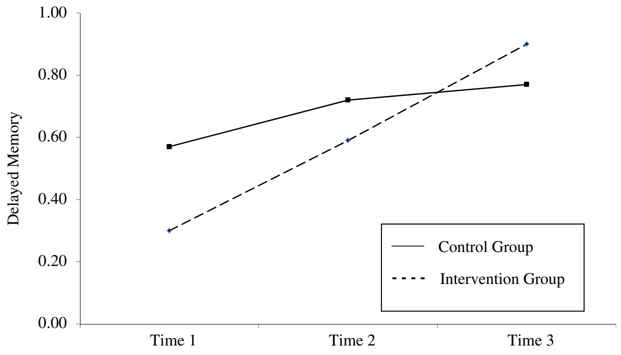
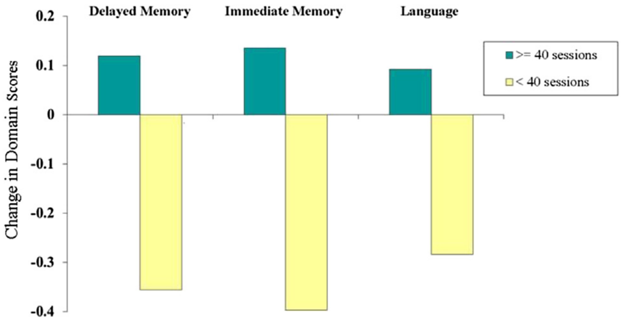


FIGURE 3. Change in cognitive domain Z scores for participants playing at least 40 sessions compared with those playing less than 40 sessions.



had played at least 40 sessions (N = 52) showed a significant improvement in all three cognitive domains compared with those who had played less than 40 sessions (N = 17) (Delayed Memory: t(67) = 3.0, p = 0.004; Immediate Memory: t(67) = 3.4, p = 0.001; and Language: t(67) = 2.2, p = 0.03; Fig. 3). These two sets of participants did not differ on any of the demographic or neuropsychological test scores at baseline.

DISCUSSION

These findings indicate that the use of a computerized memory/brain training program leads to improved delayed memory scores after 2 months and 6 months. Volunteers in the control group did not show cognitive improvement initially after 2 months so practice effects were not obvious. In addition to individuals enrolled in the intervention arm, we examined a dose-dependent relationship and found that anyone (intervention or control) who had the opportunity to play more than 40 sessions during the duration of the study improved in terms of both memory (immediate and delayed recall) and language abilities. These results suggest that this form of computerized cognitive training may have its greatest benefit when used consistently for at least 2 months (or the equivalent of 40 sessions) or more.

These results augment previous findings from studies of computerized cognitive training techniques. For example, a pilot study examining the use of a computerized program developed by Posit Science found an improvement in objective measures of overall cognitive functioning, but no improvements were found in memory and language;[27] the effect size of this intervention was 0.33 SD and was nonsignificant. These results are similar to our effect size at the 2-month (0.33) and the 6-month mark (0.67). However, we note that it is difficult to compare the two programs, because Posit Science primarily focused on information processing speed and accuracy, with memory tasks indirectly merged into the exercises; whereas the tasks within the current computerized training program included memory, critical thinking, visual spatial, mental calculation, and language. Another difference between the studies is session duration: One session in the Posit Science computerized program lasts 100 minutes, whereas one session in the Dakim computerized program lasts only 20–25 minutes.

Although the participants in our population represent an educated sample, it is likely that we would find similar results in a more diversely educated sample based on longitudinal observational studies. For instance, based on the Bronx Aging Study, self-reported cognitive leisure activities (i.e., crossword puzzles, reading) were associated with delayed onset of memory decline and were independent of education in healthy aging individuals.[28] In fact, Hall et al.[28] indicated that each additional self-reported day of cognitive activity delayed the onset of memory decline by 0.18 years. Taken together, these findings suggest that cognitively stimulating activities may contribute to an individual's cognitive reserve, independent of education. Our current study and the Bronx Aging Study likely indicate that it is the cumulative effect of participating in cognitive activities that appears to provide most benefit.

Although we were able to demonstrate cognitive benefits from use of the current computerized program on its own, combining a computerized cognitive training program with an overall healthy lifestyle could provide additional benefits. In our previous research,[22] we developed and implemented a 6-week, 12-session program that focused on teaching memory techniques to improve everyday memory challenges and on brain healthy strategies (i.e., diet, exercise, stress reduction). Results showed improved objective memory performances (i.e., recall, recognition, and retention for new verbal information) and subjective memory scores after just 12 hours of instruction. Similarly, we previously implemented a 14-day program focused on an overall healthy lifestyle that included daily memory training exercises.[29] We found positive results as measured by more efficiency in brain functioning and improved language scores. It is likely that participating in activities such as the current computerized program, in conjunction with an overall lifestyle approach, would further enhance memory and language performances after the intervention and possibly at long-term follow-up as we have seen in previous studies such as the ACTIVE study[16] and the IMPACT study.[19]

Given the few studies examining the efficacy of computerized cognitive training programs, the current findings provide several implications. First, although other studies have indicated improved attention and memory after only 2 months of computerized training program compared with no exposure,[19] the current study demonstrated that extended use of the computerized program across a longer duration (6 months) improved delayed memory. Second, the current study demonstrated improvements in language, which has been implicated to be the primary symptoms of clinical manifestations of Alzheimer disease.[30–34] Thus, these findings suggest that engaging in a computerized brain fitness program over an extended duration can improve cognitive performance, including memory and language.

We recognize that limitations to this study include a relatively small sample size, a comparatively short follow-up period of 6 months, and that most participants were white and well educated. We also recognize that the groups (intervention and control) did not have the same opportunities (i.e., the control group played for a prescribed 2-month time period after the wait period for a set number of sessions) and that there was a wide variability (as seen in the ranges and SDs) in the number of sessions played in both groups, thus limiting the comparisons between the two groups. We also recognize that some participants may have met criteria for mild cognitive impairment and that the possible variability in cognitive skills (memory, attention, executive functioning) may have added noise to the overall findings (although statistically significant differences were not found and thus did not need to be controlled for). Future research should aim to expand the sample size, the length of follow-up, and study a more diverse population (ethnicity, education, age).

Further studies are needed to better understand how improved test scores after an intervention, such as brain fitness exercises, translate to everyday life skills and functional abilities. In addition, it will be important to examine prospective benefits (<5 years) of brain fitness programs on cognitive measures to better understand the necessary duration for maximum benefit from computerized programs, whether a specific "dose" is needed (i.e., how many sessions or how many hours) to reach maximum benefit, and whether ongoing "booster sessions" would be necessary to maintain the results (i.e., improved memory). Currently, a large randomized controlled trial (Iowa Healthy and Active Minds Study; N = 681) is in progress to examine if a home-based computerized training program or an on-site program will result in better cognitive performance, given individual dosing and maintenance.[35] Such findings would not only further validate the benefits of computerized programs, but would also encourage the regular use of computerized programs and the accessibility of such programs to older adults in their home.

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