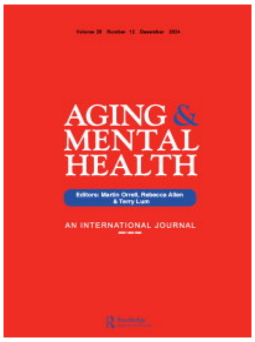


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# A self-guided e-learning program improves metamemory outcomes in healthy older adults: a randomized controlled trial

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**ABSTRACT**

**Objectives:** Aging brings memory changes that can be concerning for some older adults. Whereas in-person memory interventions can positively impact knowledge, mental health, and behavioural outcomes, self-guided e-learning programs may offer scalable and accessible alternatives to in-person programming. The current study aimed to evaluate efficacy of an e-learning program compared to no treatment.

**Method:** The trial was registered at ClinicalTrials.gov (NCT03602768). As part of a larger, multi-arm, controlled trial, healthy older adults (ages 60-84, 71% female) were randomized into an intervention or a delayed-start control condition. Data collection personnel were masked to participant grouping. Outcome measures were completed through telephone interviews and online questionnaires at baseline, immediate post-intervention, and 6- to 8-week follow-up.

**Results:** Among 115 analyzed participants, there were larger improvements over time in memory knowledge, memory strategy acquisition and daily use, and self-reported memory satisfaction and ability in the group that completed the intervention than in the control group. There was no interaction effect for health-promoting behaviors. Intention-to-treat analyses showed attenuated but largely similar findings.

**Conclusion:** This self-guided e-learning memory program demonstrated similar clinical outcomes provided by in-person, facilitator-led programs. It may serve as an effective first-line treatment for older adults presenting with memory concerns in clinical settings.

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**KEYWORDS**
Metacognition; computer-assisted instruction; outcome assessment; healthy lifestyle; memory and aging program

## Introduction

Memory changes are among the most robust and pervasive age-related changes in cognition (Salthouse, 2019). Many older adults report memory difficulties such as learning new names or remembering where they put something (Ossher et al., 2013), and the estimated prevalence of these subjective memory complaints in this population ranges from 25-50% (Jonker et al., 2000). For many older adults, memory changes can lead to significant worries (Jessen et al., 2020) and can impact their feelings and views of themselves, their relationships and social interactions, their work, and their recreational activities (Parikh et al., 2016).

Providing timely, accessible education and support has the potential to address mental health concerns, empower older adults to optimize their brain health, and help direct those needing medical follow-up to the appropriate resources. An increasing number of training programs and interventions have been created to target age-related memory decline and bolster memory confidence (e.g. Belleville et al., 2006; Kinsella et al., 2016; Troyer, 2001). A common underlying drive for such programs is the idea that cognitive health across the lifespan can be mediated in a positive direction by memory training and psychoeducation about modifiable lifestyle factors that promote brain health (Hertzog et al., 2008; Livingston et al., 2024). As such, these programs may include direct training of cognitive processes, training to use compensatory strategies, and modification of lifestyle behaviors such as exercise, diet, sleep, and stress management.

Overall, research shows that memory interventions can increase perceived memory abilities and strategy use while increasing psychological well-being, mental health, and overall quality of life (Hudes et al., 2019; Sella et al., 2023). Systematic reviews have identified educational interventions as most effective (in comparison to physical intervention, cognitive training, and pharmacological treatments) in improving memory performance in individuals with self-reported cognitive decline (Metternich et al., 2010; Roheger et al., 2021). As societies around the world continue to recognize the need to support individuals in maintaining independence and functioning during later life, it is important to evaluate the efficacy and accessibility of interventions designed for older adults. Considering cost-effectiveness, limitations of accessing in-person programs, and a healthcare landscape rapidly incorporating virtual service delivery, our team sought to develop a self-guided, e-learning memory program.

Our e-learning program was modeled after the Memory and Aging Program®, a 5-week in-person psychoeducation and memory-strategy training intervention developed and offered for 25 years at Baycrest (Troyer, 2001; Troyer & Vandermorris,

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2012a). The program is intended for healthy older adults who are concerned about their memory or are interested in optimizing their brain health and memory functioning. The program focuses on teaching and applying evidence-based external and internal memory strategies applicable to real-life scenarios. This teaching is built on a holistic foundation, including biological, psychological, social, and environmental determinants of cognitive health in older adults. The program incorporates a variety of behavior-change techniques—including self-efficacy, cost-benefit analysis, accountability, and ensuring successful experiences—to facilitate decisions related to both the initiation and maintenance of behavior change, consistent with current theories of self-regulation and behaviour change (Rothman, 2000; Rothman et al., 2011). Previously demonstrated benefits of the in-person program include gains in memory knowledge and strategy use, increased satisfaction and confidence with one's everyday memory functioning, positive behavioural change in healthy lifestyle domains, decreased intentions to seek unnecessary medical attention for memory concerns, and feelings of acceptance and reduced anxiety about normal age-related memory changes (Troyer, 2001; Vandermorris et al., 2017; Vandermorris et al., 2022; Wiegand et al., 2013).

The design and development of the online program involved a multidisciplinary team of researchers, clinical neuropsychologists, and instructional design and e-learning development experts. Utilizing an agile developmental cycle (i.e. a flexible and iterative approach to design, piloting, and modification) and the framework of the Harvard Clinical and Translation Science Center's translational phases (Harvard Catalyst, 2021) the program was co-designed with community-dwelling older adult users through multiple iterations of design and feedback (Yusupov et al., 2022). Participants indicated that the e-learning program was user-friendly and enjoyable to use. Baseline and post-intervention evaluations identified satisfaction with program-specific goals, increased memory knowledge and strategy use, and the adoption of healthier lifestyle behaviours.

The objective of the current study was to evaluate the online program using rigorous methodology—a randomized controlled trial—to provide the highest level of evidence for the efficacy of an intervention. The guiding framework for this study comes from previous research demonstrating that in-person memory programs can provide meaningful benefits to older adults (Hudes et al., 2019) and recent survey results indicating that the large majority of older adults are comfortable using technology and the internet (AGE-WELL, 2020; Pew Research Center, 2022). Specifically, our aim was to test for post-intervention benefits that were consistently observed with previous evaluations of the in-person Memory and Aging Program (Troyer, 2001; Vandermorris et al., 2017; Vandermorris et al., 2022; Wiegand et al., 2013) when compared to no treatment for healthy older adults with normal age-related memory concerns. Because the online program was designed to be similar to the in-person version in terms of content, activities, level of engagement, and integration of behavior-change techniques, we expected similar types of outcomes between the two versions. Thus, we expected participants in the intervention group to demonstrate greater knowledge about memory and brain health, improved acquisition of practical memory strategies, increased confidence and satisfaction with memory, and greater participation in health-promoting lifestyle behaviors, when compared to a control group.

## Method

### *Participants and procedure*

Figure 1 shows the flow of participants through the trial. The current study was a part of a larger, multi-arm, controlled trial with healthy older adults recruited between March 2018 and December 2020. Recruitment was done on a rolling basis through online advertisements shared on social media, email lists from organizations for older adults (Cogniciti and Canadian Association of Retired Persons), and an institutional volunteer pool. The recruitment advertisement targeted individuals interested in cognitive fitness, aging, and brain health and specified that the study involved testing online interventions for common age-related cognitive changes that were based on well-validated, in-person programs offered at the host institution. Ethics approval was obtained from Baycrest's Research Ethics Board (#17-24) and was in accordance with the Helsinki Declaration. The study was prospectively registered (https://clinicaltrials.gov/study/NCT03602768).

The 1320 individuals who replied to the online advertisement received a study information sheet and informed consent form by email. After obtaining informed consent, prescreening was conducted online and by telephone. A total of 394 participants met the following inclusion criteria: age 60 and older, self-reported English proficiency, interest in learning how to improve cognitive functioning, access to and familiarity with computers, self-reported independence in activities of daily living, absence of self-reported major health conditions affecting cognition (e.g. stroke, brain injury, and other neurological disorders), mental status in the unimpaired range (i.e. $\geq 30$ on the Modified Telephone Interview for Cognitive Status, mTICS; Brandt et al., 1988), and low endorsement of depression symptoms (i.e. $< 10$ on the Patient Health Questionnaire, PHQ-9; Kroenke et al., 2001). In addition, participants had to endorse at least one cognitive complaint such as difficulty remembering names, focusing attention, remembering the location of items, remembering intentions, or solving problems. Primary reasons for exclusion of potential participants are shown in Figure 1.

The 394 eligible participants were emailed a link to complete the baseline outcome measures described below. Participants were then randomly assigned to one of two conditions within one of two studies. Both studies included a treatment arm and a control arm. The other study was an evaluation of Goal Management Training®, an intervention for executive function, the results of which will be reported separately. A blocked randomization scheme stratified by age (60-69 and 70+) was created using an online software application (Sealed Envelope Ltd., 2017). The randomization list was managed by a team member not known to participants or involved in data collection. Of the 394 eligible participants, 202 were assigned to either the intervention or control arm of the current study. Individuals assigned to the control condition were offered the opportunity to participate in the program once all assessment sessions were completed.

Recruitment materials and study procedures were constructed to support participant perception of clinical equipoise between conditions. Specifically, study details did not specify at which point of participation access to the e-learning program would be provided. In addition, team members involved in data collection were masked to participant grouping. Participants randomized to the intervention condition were emailed a link to access the e-learning Memory and Aging Program remotely from their homes or location of

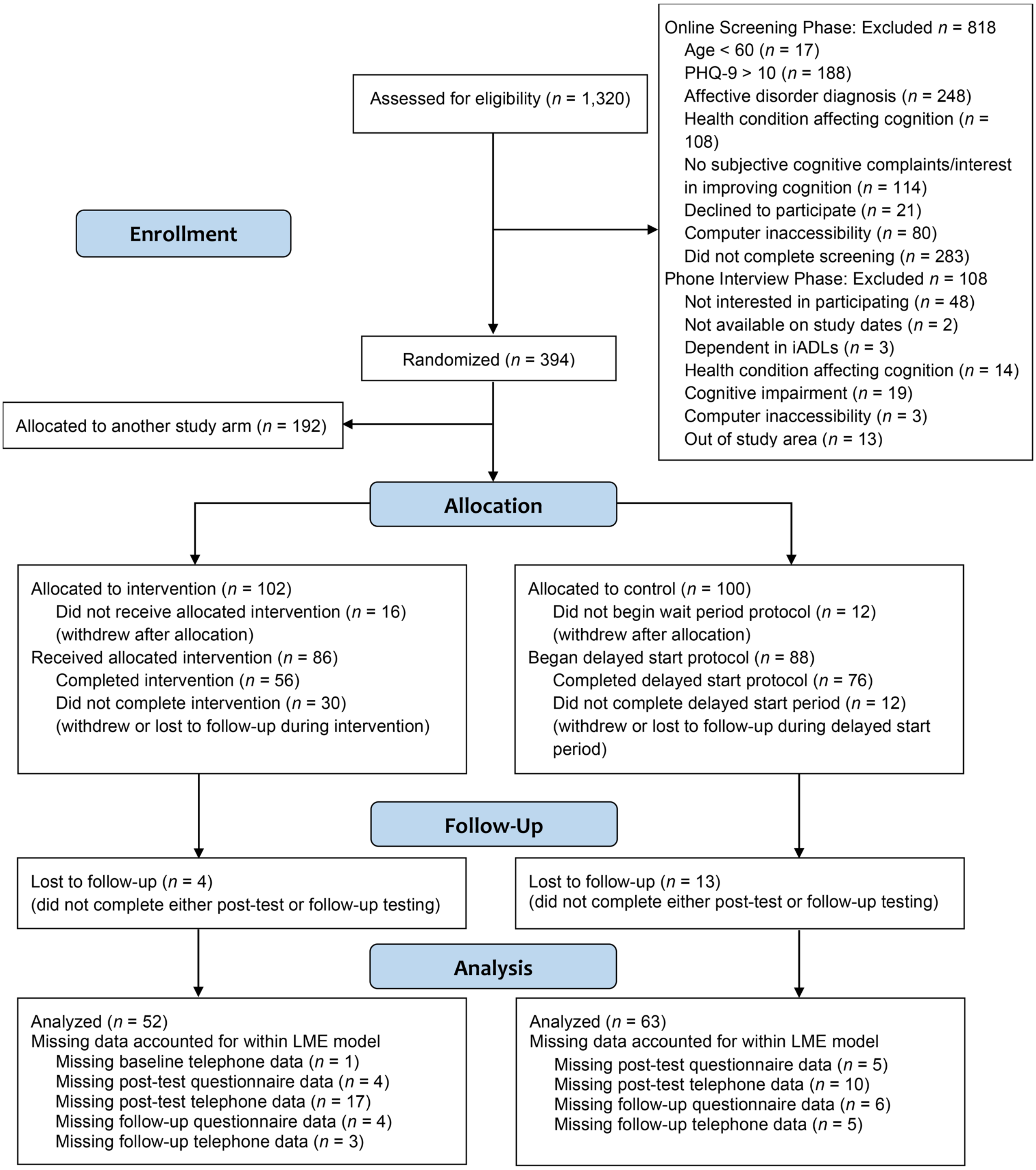


**Figure 1.** Flow diagram of participant progress through the phases of the randomized trial.
*Note.* PHQ-9 = Patient Health Questionnaire-9; iADLs = instrumental activities of daily living; LME = linear mixed effects.

choice. Outcome measures were administered through telephone interviews and online questionnaires at three time points: baseline, immediately post-intervention, and 6- to 8-week follow-up for the intervention group, with corresponding time points for the control group. Participants were compensated $30 CAD for each completed testing session for a maximum of $90 CAD.

### *Self-guided e-learning memory and aging program*

The program has been described in detail previously (D'Amico et al., 2024; Yusupov et al., 2022). Briefly, the program consisted of eight modules, requiring approximately 10 h of engagement overall. Supplementary Table 1 provides an overview of program content. Participants were asked to complete approximately one module per week but were given the flexibility to complete the modules at their preferred pace. Participants were required to complete each module in order.

Program content and activities were delivered in a variety of formats, including videos, animations, interactive games, and discussion boards (online forums) to support individual differences in learning styles and enhance participant interaction (Yusupov et al., 2022). A workbook (Troyer & Vandermorris, 2012b) mailed to each participant at the onset of the intervention provided a summary of program content and homework assignments. The feasibility, acceptability, and impact of the self-guided e-learning program are reported elsewhere (D'Amico et al., 2024).

## Outcome measures

### Memory and brain health knowledge

The Memory Knowledge Quiz was adapted from previous evaluations of the in-person Memory and Aging Program (Troyer, 2001; Troyer & Vandermorris, 2012a). Over the telephone, participants were asked 12 open-ended questions related to memory and brain health. Each answer was scored using a scoring rubric of acceptable responses, for a total of 25 possible points.

### Memory strategy application

The Memory Strategy Toolbox was administered online. Participants were presented with six common memory-demanding scenarios (e.g. learning a new name) and were asked to list memory strategies that would be useful for each situation (e.g. repeat the name, write it down, pay attention; Troyer, 2001). Responses were scored according to the number of different strategies and their quality; each strategy was awarded a score from 0 (indicating an ineffective strategy or a response that is not a memory strategy, such as memorize it) to 2 (indicating effective, specific, and self-reliant strategies, such as associate it with a known name). There was no maximum score.

### Memory satisfaction, ability, and strategy use in daily life

The Multifactorial Memory Questionnaire (MMQ) was administered online and consisted of 57 items across three subscales, each rated on a 5-point Likert-type scale (Troyer & Rich, 2002). MMQ-Satisfaction measures one's satisfaction or concern for memory with scores ranging from 0 to 72. MMQ-Ability measures perceptions of one's memory ability with scores ranging from 0 to 80. MMQ-Strategy measures the frequency of memory strategy use in daily life with scores ranging from 0 to 76. The measurement properties of the MMQ, including factor structure, internal consistency, stability, measurement error, and validity, have been reported in a number of studies and a meta-analysis (Shaikh et al., 2021; Troyer et al., 2019).

### Healthy lifestyle behaviors

The Health Promoting Lifestyle Profile II (HPLPII) was administered online and consisted of 52 items rated on a 4-point Likert-type scale to measure the frequency of healthy behaviors (Walker et al., 1987). The questionnaire provides a score for six domains: health responsibility, physical activity, nutrition, spiritual growth, interpersonal relations, and stress management. Mean frequencies were computed for each domain ranging from 1 to 4, and an overall score was computed summing responses from all 52 items for a total possible score of 208. Higher scores indicate greater frequency of participant-reported healthy behaviors in daily life. Psychometric properties of the HPLPII, including factor structure, internal consistency, and reliability, have been previously reported (Walker et al., 1987).

## Statistical analyses

To determine study sample size, we calculated change scores among participants and controls in previous evaluations of the in-person Memory and Aging Program, which indicated effect sizes ranging from medium to large (0.6 to 0.7). Thus, with a desired power of 0.9 and effect size of 0.6, Cohen's sample size table (1988) indicated at least 49 subjects in each group would be necessary to detect a statistically significant difference at $p = 0.05$.

Our primary analyses were conducted in RStudio version 1.3.1093 with the following packages: psych (Revelle, 2018), nlme (Pinheiro et al., 2007), stringr (Yarberry, 2021), and spida2 (Monette et al., 2018). Group differences in age, years of education, and mTICS scores were assessed with *t*-tests; group differences in sex were examined with a chi-square analysis. A review of the raw data indicated that assumptions of linearity, homogeneity of variance, and normality were met. Linear mixed-effects models were run on all four outcome measures (treated as continuous) to assess baseline differences between the two groups (intervention and control), group-by-time interactions (baseline, post-intervention, follow-up), and maintenance at follow-up of post-intervention main effects.

Group and time were set as fixed effects, and participants were treated as a random effect. Wald tests were conducted to examine the interaction effects within each model. Package spida2 was designed to handle data missing at random (reflected in the models' standard error and confidence intervals), which included 6% missing data in outcomes assessed through the online questionnaires (including the Memory Strategy Toolbox, the MMQ, and the HPLPII) and 10% missing data in the Memory Knowledge Quiz, which was administered by telephone. The package employs well-established techniques, notably maximum likelihood estimation, to address missing data while making efficient use of available information. Cohen's *d* effect sizes were calculated using the reported test statistics and degrees of freedom; 0.2, 0.5, and 0.8 correspond to small, medium, and large effect sizes, respectively (Cohen, 1988). Unstandardized parameters were used for reporting, and a nominal alpha level was set at 0.05.

Sensitivity analyses were conducted to mitigate overestimation of treatment effects, preserve the principle of randomization, minimize the risk of selection bias due to differential attrition, reflect realities of treatment adherence in clinical practice, and provide information related to the clinical utility of the program (Brody, 2016). These analyses were conducted using IBM SPSS Statistics 25. An intention-to-treat analysis was conducted including all participants who were initially randomized into the intervention or control condition and who had baseline data (Gupta, 2011). The last-observation-carried-forward approach was used to impute values for missing observations. Specifically, baseline data were carried forward for both the post-intervention and follow-up time points. A repeated-measures analysis of variance (ANOVA) was conducted, followed by post-hoc analyses of any significant interaction to assess effect sizes.

To enhance understanding of clinical utility, the number needed to treat in order to achieve one successful outcome from baseline to post-intervention was calculated on a per protocol basis (i.e. including only participants who completed the study protocol) and an intention-to-treat basis (i.e. including all participants who were randomized) for any statistically significant effects (Cook & Sackett, 1995). Successful outcomes were defined by computing reliable change indices for outcome measures with a reported reliability coefficient (i.e. MMQ and HPLPII) in order to calculate the standard error of the difference and z-score; positive reliable change indices greater than 1.96, representing $p < 0.05$ in a normal distribution, were categorized as successful outcomes (Jacobson & Truax, 1991). For the Memory Knowledge Quiz and the Memory Strategy Toolbox questionnaire, a successful outcome was defined as an increase of one standard deviation or more from baseline to post-intervention. Participants with missing data were categorized as showing 'no change.'

## Results

### Participant characteristics

Demographic information for the intervention and control groups is presented in Table 1. Of the 115 participants whose data were included in the main analyses, 71% were female, and ages ranged from 60 to 84 years ($M=70.3$, $SD=6.3$). Overall, participants were highly educated ($M=15.7$, $SD=2.2$, range = 10-20 years) and had a mean mTICS score of 39.3 ($SD=3.9$, range = 31-49). The groups did not differ on these variables ($ps>0.05$), and effect sizes were negligible.

An additional 87 participants withdrew or were lost to follow up. Reasons for attrition were provided by some participants, and these included a breakdown in communication, personal circumstances, and dissatisfaction with the e-learning program. Supplementary Table 2 provides demographic information and baseline data from outcome measures for 115 participants who were included in the study sample and 87 participants who withdrew or were lost to follow-up. The study group was younger than the attrition group ($Ms=70.3$ and 73.4 years, respectively), $t(199)=-3.14$, $p=0.002$, and more highly educated ($Ms=15.7$ and 15.0 years, respectively), $t(199)=2.06$, $p=.04$. There was a small difference in scores on the Memory Knowledge Quiz, with the study group scoring higher at baseline than the attrition group ($Ms=9.4$ and 8.4), $t(176)=-1.99$, $p=.049$. The study group had a lower rate of missing Memory Knowledge Quiz data ($n=1$) compared to the attrition group ($n=27$). There were no significant group differences in sex, cognitive performance on the mTICS, or any other outcome measure at baseline ($ps>0.05$), with small to negligible effect sizes.

### Treatment adherence

For the 56 participants who completed the intervention, the mean time between starting and finishing the self-paced program was 9.7 wk (median = 8, range = 1-48). They completed 30 or 31 of the individual program components (e.g. discussions, modules, games); 95% of these participants completed all 31 components. Homework completion was not recorded.

### Outcome measures

Descriptive statistics for all outcome measures are provided in Supplementary Table 3. There were no significant differences between the intervention and control groups at baseline on any outcome measure ($ps>0.05$).

### Memory and brain health knowledge

Results are shown in the top panel of Figure 2. There was a significant group-by-time interaction on the Memory Knowledge Quiz, with Wald tests specifying a large significant difference between groups at post-test, $B=6.38$, $SE=0.71$, $p<0.001$, 95% CI [4.98,7.78], $d=0.80$, and a medium significant difference at follow-up, $B=4.54$, $SE=0.66$, $p<0.001$, 95% CI [3.25,5.84], $d=0.62$, in favor of the intervention group. There was a small significant decline in scores from post-test to follow-up within the intervention group, $B=-1.84$, $SE=0.73$, $p=0.01$, 95% CI [-3.27,0.40], $d=0.23$.

### Memory strategy application

Results are shown in the bottom panel of Figure 2. There was a significant group-by-time interaction on the Memory Strategy Toolbox questionnaire, with Wald tests specifying a medium significant difference between groups at post-test, $B=4.94$, $SE=0.82$, $p<0.001$, 95% CI [3.33,6.56], $d=0.56$, and at follow-up, $B=4.06$, $SE=0.83$, $p<0.001$, 95% CI [2.43,5.68], $d=0.43$, in favor of the intervention group. Post-intervention gains were maintained at follow-up within the intervention group, $B=-0.89$, $SE=0.85$, $p=0.30$, 95% CI: [-2.56,0.79], $d=0.09$.

**Table 1.** Participant demographics by study group.

| | Intervention ($n=52$) *M (SD)* | Control ($n=63$) *M (SD)* | Effect Size |
|---|---|---|---|
| Age (years) | 70.0 (6.8) | 70.6 (5.9) | $d=0.09$ |
| Education (years) | 15.4 (2.1) | 15.8 (2.3) | $d=0.19$ |
| Female (proportion) | 71% | 71% | $w=0.00$ |
| mTICS (total score) | 39.2 (4.2) | 39.3 (3.6) | $d=0.04$ |

*Note.* mTICS = Modified Telephone Interview for Cognitive Status. Years of education were coded according to the highest level of education achieved. Significant group differences were not detected for any of these variables. Ethnicity/race data were not collected.

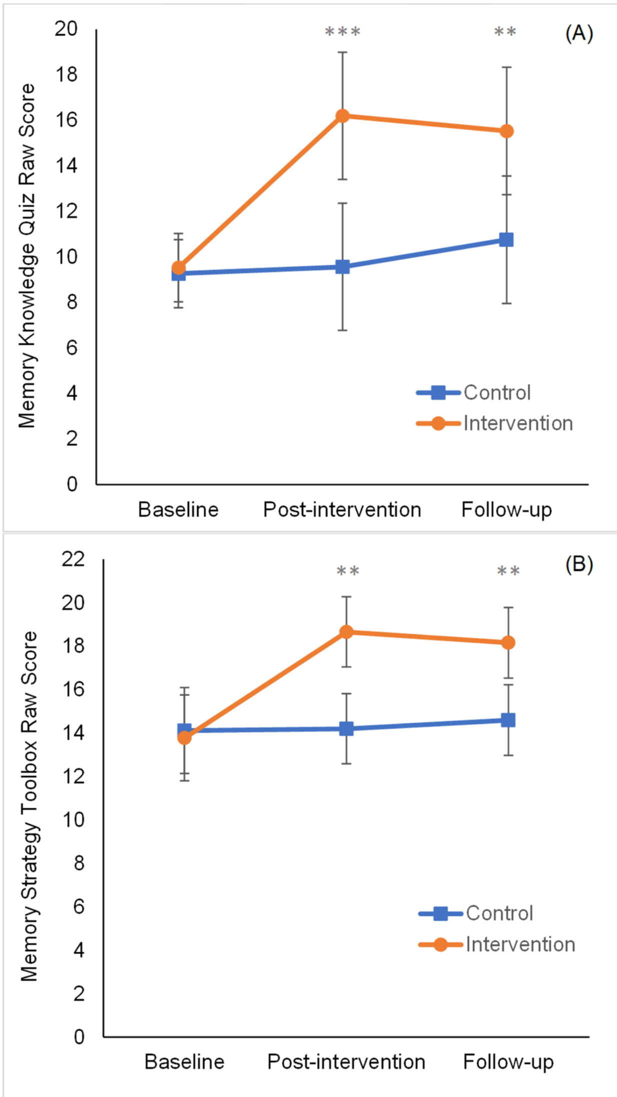


**Figure 2.** Group performance on measures of knowledge and strategy application.
*Note.* Error bars represent 95% confidence intervals. Panel A: Scores on the Memory Knowledge Quiz. The maximum possible score on this measure is 25 points; in this sample, scores ranged from 2 to 25. Panel B: Scores on the Memory Strategy Toolbox. Raw scores on this measure have no maximum; in this sample, scores ranged from 5 to 40.
**medium effect size.
***large effect size.

### Memory satisfaction, ability, and strategy use in daily life

Results are shown in Figure 3. There was a significant group-by-time interaction on metamemory scores within each domain of the MMQ. There was a small significant difference between groups at post-test for memory satisfaction, $B = 3.47$, $SE = 1.42$, $p = 0.015$, 95% CI [0.68,6.26], $d = 0.22$, and memory ability, $B = 4.64$, $SE = 1.53$, $p = 0.002$, 95% CI [1.64,7.63], $d = 0.27$, and a small to medium difference for strategy use in daily life, $B = 6.78$, $SE = 1.50$, $p < 0.001$, 95% CI [3.82,9.73], $d = 0.40$, in favor of the intervention group. There was a small significant difference at follow-up for memory satisfaction, $B = 4.26$, $SE = 1.43$, $p = 0.003$, 95% CI [1.46,7.05], $d = 0.27$, and strategy use, $B = 5.63$, $SE = 1.51$, $p < 0.001$, 95% CI [2.66,8.61], $d = 0.33$, but not for memory ability, $B = 2.70$, $SE = 1.53$, $p = 0.08$, 95% CI [-0.30,5.71], $d = 0.16$. Post-intervention gains were maintained at follow-up within the intervention group for memory satisfaction, $B = 0.78$, $SE = 1.47$ $p = 0.59$, 95% CI [-2.10,3.67], $d = 0.05$, memory ability, $B = -1.94$, $SE = 1.57$, $p = 0.22$, 95% CI [-5.03,1.16], $d = 0.11$, and memory strategy use, $B = -1.15$, $SE = 1.56$, $p = 0.46$, 95% CI [-4.21,1.92], $d = 0.07$.

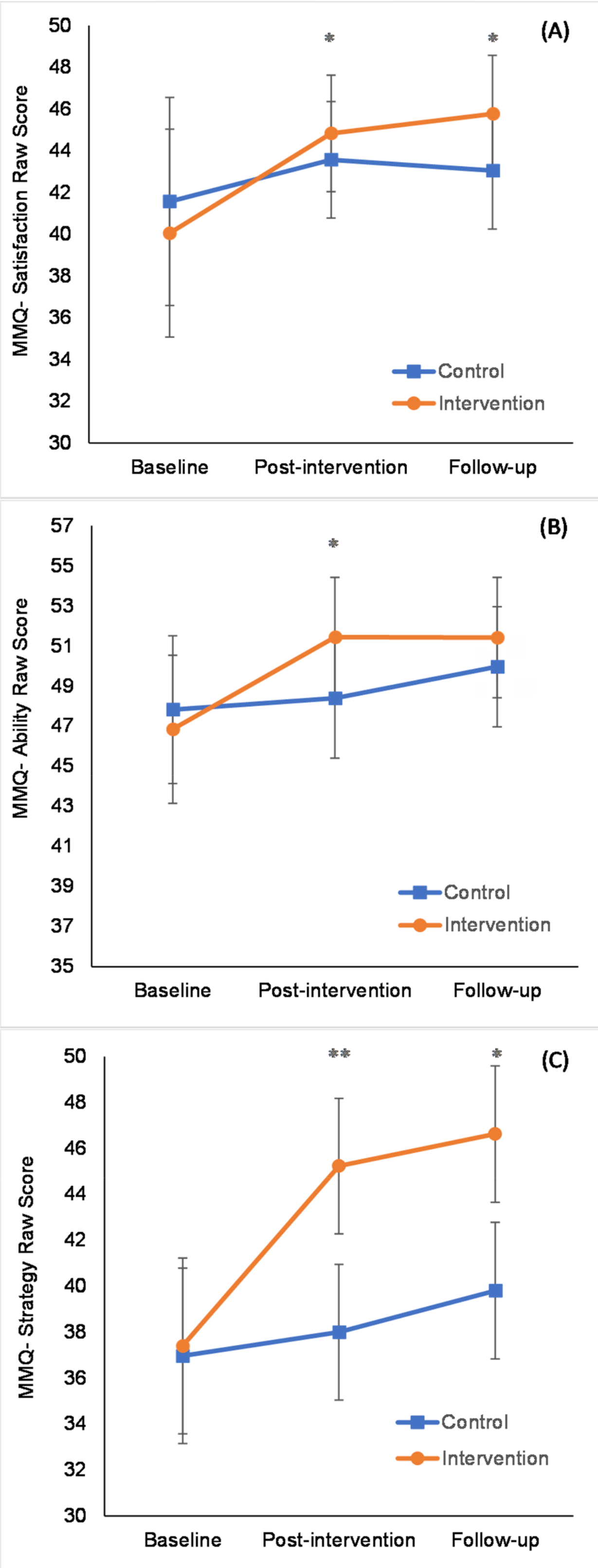


**Figure 3.** Group performance on measures of metamemory.
*Note.* Y-axis scale does not begin at zero. Error bars represent 95% confidence intervals. Panel A: Scores on Multifactorial Memory Scale (MMQ)-Satisfaction. Raw scores on this measure are out of a maximum of 72; in this sample, scores ranged from 7 to 71. Panel B: Scores on MMQ-Ability. Raw scores on this measure are out of a maximum of 80; in this sample, scores ranged from 21 to 75. Panel C: Scores on MMQ-Strategy. Raw scores are out of a maximum of 76; in this sample, scores ranged from 16 to 72.
*small effect size.
**medium effect size.

### Healthy lifestyle behaviors

As seen in Figure 4, there were no significant group-by-time interactions for the total HPLPII score at post-test, $B = -0.94$, $SE = 2.17$, $p = 0.66$, 95% CI [-5.20,3.31], $d = 0.04$, or at follow-up, $B = 2.32$, $SE = 2.17$, 95% CI [-1.95,6.60], $p = 0.29$, $d = 0.09$. Similarly, no interactions were detected within any of the six individual domains, including health responsibility, physical activity, nutrition, spiritual growth, interpersonal relations, and stress management.

## Sensitivity and effectiveness analyses

### Intention-to-treat (ITT) analyses

A total of 102 participants in the intervention group and 100 participants in the control group completed baseline online questionnaires and were included in the ITT analyses for these measures. A subset of these participants did not complete baseline telephone assessment. Thus, for the Memory Knowledge Quiz, 89 intervention participants and 86 control participants were included in the ITT.

ITT analyses are presented in Supplementary Table 4. To summarize, these analyses showed the same patterns of findings as

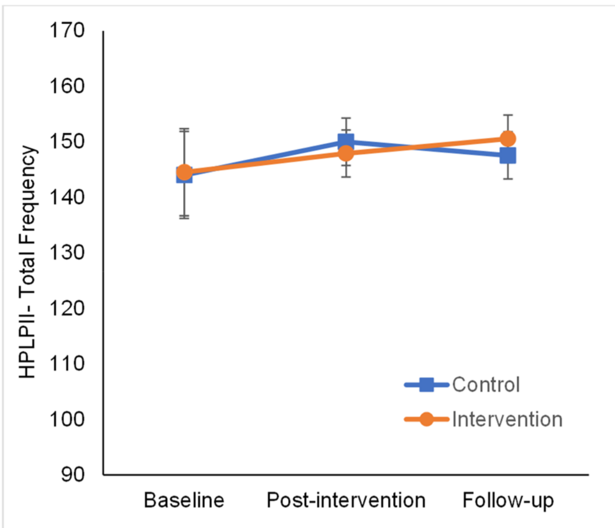


**Figure 4.** Group total frequency of health-promoting lifestyle behaviors.
*Note.* Y-axis scale does not begin at zero. Error bars represent 95% confidence intervals. The maximum possible score on this measure is 208; in this sample, scores ranged from 93 to 198.

the main analyses for most variables. There were significant yet attenuated group-by-time interactions for the Memory Knowledge Quiz, Memory Strategy Toolbox, MMQ-Satisfaction, and MMQ-Strategy, and no interaction for the HPLPII. In contrast, the group-by-time interaction for MMQ-Ability that was identified in the main analysis was not significant in the ITT analysis.

### *Number needed to treat (NNT)*

Using a one standard deviation increase as the definition of a successful outcome from baseline to post-test on a per protocol basis, the NNT was 1.6 for memory knowledge and 2.3 for application of memory strategies. Rounding upwards, this means that two to three people need to complete the e-learning program for one person to have a successful knowledge or application outcome over and above what is expected by chance. The NNTs calculated on an ITT basis were 3.9 and 4.8, respectively. This captures the number of persons likely to benefit in the common clinical scenario where the program is recommended, but follow-through is not consistent. A clinician could reasonably expect that one of every four to five persons referred to the program would follow-through and experience benefit.

For the remaining measures, successful outcomes were defined by improvements in excess of the reliable change index. For satisfaction with memory, the reliable change index of 13.3 resulted in NNTs of 11.5 calculated per protocol, and 28.0 calculated on an ITT basis. For memory ability, the reliable change index of 9.4 showed NNTs of 6.2 per protocol and 15.5 ITT. For memory strategy use, the reliable change index of 8.4 showed NNTs of 3.3 per protocol and 6.8 ITT.

To explore possible differential effects of the intervention by gender and education, we examined the number of men versus women and university-educated versus non-university-educated participants who showed successful outcomes versus no change on each outcome measure in a series of $2 \times 2$ chi-square analyses. None of these analyses showed significant effects of gender or education on any outcome measure, all $\chi^2$s $< 3.3$, all *p*s $> 0.07$.

## Discussion

The present study showed that a self-guided e-learning program has a meaningful effect on memory knowledge, strategy application and use, and metamemory in a group of healthy older adults between the ages of 60 and 84. Prior pilot studies have indicated potential benefits of online memory intervention (Pike et al., 2023; Yusupov et al., 2022), and the current study is the first to use a randomized controlled trial to provide the highest level of evidence for intervention outcomes. Consistent with study hypotheses, participants who completed the intervention demonstrated significant initial and sustained improvements in knowledge of memory and brain health as well as the application of effective memory strategies, with medium to large effect sizes and NNTs of about 2. This was the most robust and consistent finding documented during evaluations of the in-person version of the Memory and Aging Program (Troyer, 2001; Vandermorris et al., 2022; Wiegand et al., 2013).

In addition, participants who completed the intervention made significant initial metamemory gains that were maintained over time, with NNTs ranging from 3 to 11. Specifically, participants who completed the intervention indicated greater satisfaction with their memory, fewer everyday memory mistakes, and an increased frequency of memory strategy use in daily life relative to the control group. The size of these effects ranged from small to medium in the current study, whereas the gains in metamemory from the most recent in-person evaluation ranged from medium to large (Vandermorris et al., 2022). Although the current study was not designed to test differences between self-guided versus facilitator-led intervention, these results suggest a possible smaller effect of the former. This may not be surprising, given that in-person interventions inherently encompass a broader range of behavior-change techniques such as social expectancies and accountability than do online interventions.

Evaluating the results within the context of ITT analyses provides insights into the effectiveness of the intervention more closely reflecting the practical reality of clinical intervention studies. Because ITT analyses include all randomized participants regardless of whether they were lost to attrition or completed the study protocol, they account for some degree of nonadherence to health interventions, as would be expected in real-world clinical settings. Within this context, the gains in knowledge and strategy application remained robust. Findings associated with metamemory outcomes were somewhat attenuated due to the conservative nature of the ITT approach, and notably, the group-by-time interaction for self-reported memory ability was no longer significant. Thus, although ITT analyses showed smaller effects, as expected, the pattern of findings was largely retained.

We did not achieve health-promoting behavior change findings as seen in the in-person study (Vandermorris et al., 2022). There are several possible explanations for this. Participation in in-person intervention programs involves inherent behavioral activation that may serve as a catalyst for greater behavior change. For example, participants must physically travel to the program site and may make new social connections with other program participants. Some of these activities may directly impact scores on the HPLPII's physical activity and interpersonal relations subdomains. Further, although the e-learning program integrates many behavior-change techniques (e.g. self-efficacy, ensuring successful experiences), behavior change can also be facilitated through the expectation of sharing one's experience in a social interaction (Oussedik et al., 2017), and there may be a greater sense of accountability when participating in an intervention led by a facilitator. To improve health-related behaviour change, it may be necessary to consider providing additional resources. For example, to improve nutrition, it may be necessary to provide access to healthy meal plans, motivational reminders, or a points-based incentive system in addition to psychoeducation about nutrition (Robert et al., 2021). These are all potential areas for future research.

Overall, our sample was highly educated and predominantly women, which is typical for the types of participants who tend to seek out memory intervention programs. Our exploratory analyses did not reveal any differences in outcomes between men and women or between university- and non-university-educated participants, and this is consistent with our previous findings that rates of completion of this intervention did not differ by gender or education (D'Amico et al., 2024). Nevertheless, individual differences remain important issues for future research and an area of consideration in terms of equity and accessibility of healthcare services.

A challenge of online research studies is attrition and missing data. To reduce attrition, we ensured that our program was piloted and designed with feedback from community-dwelling older adults (Yusupov et al., 2022) to ensure feasibility and acceptability of the program by our target end users (D'Amico et al., 2024). We also screened for computer use and comfort as low computer literacy is a predictor of attrition for older adults participating in online intervention studies (Hurmuz et al., 2021). Attrition in the current study was 43%, which compares favorably to the average online study (i.e. 50%-71%; Boekhout et al., 2019; Hurmuz et al., 2021; Kelders et al., 2012). Our sensitivity analyses help mitigate any overestimation of treatment effects in the face of attrition, although this attrition rate does mean that people who *could have* benefitted from the intervention did not. Further information about predictors of attrition in the current trial and implications for improving retention rates are provided elsewhere (D'Amico et al., 2024).

### *Clinical considerations*

Our study provides evidence of largely similar types of clinical outcomes obtained from a self-guided, e-learning program and the well-established facilitator-led in-person program on which it is based. Advantages of an e-learning program include potential cost savings for both the provider and the participant. For example, there are no requirements for a physical space or a clinician facilitator, and participants can minimize travel time and costs associated with attending in-person programming. General benefits of online programs include greater flexibility and a larger reach than in-person programs.

In health-care settings, this type of intervention is well suited for older adults who present with memory concerns, but do not show memory impairment on formal testing. Implementation could fit within a stepped-care model, where care is provided at various levels of intensity, and services are stepped up or down depending on client needs (O'Donohue & Draper, 2011). For older adults with subjective memory concerns in the context of normal cognition, a first step—one with low intensity but the capacity for high volume—might be this self-guided e-learning memory program. This self-directed approach may be sufficient to meet the needs of many older adults, as suggested by the NNTs derived in the current study. More intensive group or individual programming can be reserved for older adults with higher needs. Benefits to this kind of approach include more timely access to services (i.e. there are no wait times for fully self-directed resources), and the potential to save healthcare dollars by providing lower cost resources to a larger number of older adults.

## Conclusion

Through a randomized controlled trial, we demonstrated clinical outcomes of a self-guided, e-learning memory program that were similar to outcomes shown in previous research on a facilitator-led in-person version of the same program. Healthy older adults who completed the e-learning program showed significant gains in memory and brain health knowledge, acquisition of memory strategies and application in daily life, and memory satisfaction and self-reported memory ability relative to a no-intervention group. The majority of these gains were maintained over the extended follow-up period, indicating some degree of lasting effects of the intervention. There were no significant differences between groups in improvements in healthy lifestyle behaviors, which is an area of future research to inform the design of online health-promoting interventions. For older adults who are concerned about their memory changes or want to learn how to optimize brain health, self-guided, e-learning memory programming shows promise to be an effective, flexible, and cost-effective alternative to in-person programs.

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## Disclosure statement

Susan Vandermorris and Angela Troyer are co-creators of the online Memory and Aging Program. Under Baycrest's Intellectual Property Policy, they are eligible to receive a percentage of the royalties collected on the net profit generated from this venture.

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## Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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**Supplementary material**

**Supplementary Table 1**

*Description of Individual Modules Within the Online Memory and Aging Program*

| Module name | Description |
|---|---|
| Getting Started | Introduction to navigating the learning management system and program functions. |
| Module 1: Introduction | Overview of content and introduction to different components of the program (e.g., discussion boards, surveys, and polls). |
| Module 2: What is Memory? | Explanation of what memory is, brain regions involved in memory, memory processes, memory types. |
| Module 3: Factors Affecting Memory | A discussion of health and lifestyle factors that affect memory, such as medical diseases and disorders, diet, physical exercise, and cognitive engagement. Homework involved tracking physical and cognitive activity. |
| Module 4: Stress and Relaxation | A discussion of the effect of stress on memory and introduction of relaxation techniques. Homework involved tracking relaxation activities. |
| Module 5: Memory Strategies Overview & Practice Retrieval | Explanation of the rationale, procedures, and evidence supporting five key memory strategies; explanation of implementation intentions and habits as memory strategies; in-depth practice of spaced-retrieval memory strategy. Homework involved tracking the use of memory strategies. |
| Module 6: Memory Strategies Associations and Records | In-depth practice of the semantic association memory strategy and a discussion of the use of records as a memory aid. Homework involved tracking the use of memory strategies. |
| Module 7: Application of Memory Strategies & Goal Setting | Review of memory strategies and training on how to set effective goals |
| Module 8: Wrap-up & Feedback | Opportunity to participate in a content review game, goal setting, sharing final thoughts, and providing feedback |

**Supplementary Table 2**

*Participant Demographics and Baseline Outcome Measures by Study Group and Attrition Group*

| | Study Group ($n$ = 115) M (SD) | Attrition Group ($n$ = 87) M (SD) | Effect Size |
|---|---|---|---|
| Demographics | | | |
| Age (years) | 70.3 (6.3) | 73.4 (7.4) | $d$ = 0.45 ** |
| Gender (female proportion) | 71% | 66% | $w$ = 0.05 |
| Education (years) | 15.7 (2.2) | 15.0 (2.4) | $d$ = 0.29 * |
| mTICS | 39.3 (3.9) | 38.2 (4.2) | $d$ = 0.27 |
| Baseline Measures | | | |
| Memory Knowledge Quiz | 9.4 (3.3) | 8.4 (2.8) | $d$ = 0.30 * |
| Memory Strategy Toolbox | 14.0 (4.1) | 13.0 (4.2) | $d$ = 0.24 |
| MMQ-Satisfaction | 40.9 (13.7) | 44.0 (12.4) | $d$ = 0.23 |
| MMQ-Ability | 47.4 (9.7) | 50.0 (10.0) | $d$ = 0.26 |
| MMQ-Strategies | 37.2 (10.4) | 37.6 (10.1) | $d$ = 0.05 |
| HPLPII | 144.3 (20.6) | 144.1 (22.4) | $d$ = 0.01 |

*Note*. mTICS = Modified Telephone Interview for Cognitive Status; MMQ = Multifactorial Memory Questionnaire; HPLPII = Health Promoting Lifestyle Profile II.

*$p < .05$. **$p < .001$.

**Supplementary Table 3**

*Descriptive Statistics for Outcome Measures by Group and Time*

| | Intervention (*n* = 52) | | | Control (*n* = 63) | | |
|---|---|---|---|---|---|---|
| | Baseline | Post-test | Follow-up | Baseline | Post-test | Follow-up |
| Memory Knowledge Quiz | 9.5 (3.4) | 16.2 (5.0) | 15.5 (5.5) | 9.3 (3.1) | 9.6 (3.6) | 10.8 (3.7) |
| Memory Strategy Toolbox | 13.8 (4.1) | 18.7 (6.6) | 18.2 (6.8) | 14.1 (4.1) | 14.2 (5.1) | 14.6 (5.4) |
| MMQ-Satisfaction | 40.1 (15.1) | 44.8 (13.1) | 45.8 (13.1) | 41.6 (12.6) | 43.6 (13.6) | 43.1 (13.9) |
| MMQ-Ability | 46.8 (11.2) | 51.4 (9.4) | 51.4 (11.4) | 47.8 (8.4) | 48.4 (9.2) | 50.0 (10.5) |
| MMQ-Strategies | 37.4 (11.2) | 45.2 (10.2) | 46.6 (10.1) | 37.0 (9.8) | 38.0 (10.6) | 39.8 (10.4) |
| HPLPII | | | | | | |
| Health Responsibility | 2.5 (0.6) | 2.6 (0.6) | 2.6 (0.6) | 2.5 (0.4) | 2.6 (0.5) | 2.5 (0.5) |
| Physical Activity | 2.7 (0.6) | 2.8 (0.6) | 2.8 (0.7) | 2.6 (0.7) | 2.7 (0.7) | 2.7 (0.7) |
| Nutrition | 3.0 (0.6) | 3.0 (0.5) | 3.1 (0.5) | 3.0 (0.5) | 3.1(0.5) | 3.1 (0.5) |
| Spiritual Growth | 2.8 (0.4) | 2.9 (0.5) | 3.0 (0.6) | 2.9(0.7) | 3.0 (0.6) | 2.9 (0.7) |
| Interpersonal Relations | 3.0 (0.5) | 3.0 (0.6) | 3.1 (0.6) | 3.0 (0.6) | 3.1(0.6) | 3.0 (0.6) |
| Stress Management | 2.7 (0.5) | 2.8 (0.4) | 2.9 (0.5) | 2.7 (0.6) | 2.8 (0.5) | 2.8 (0.6) |
| Total Frequency | 144.5 (17.4) | 147.9 (19.2) | 150.6 (19.1) | 144.0 (23.1) | 150.0 (22.1) | 147.6 (24.3) |

*Note*. MMQ = Multifactorial Memory Questionnaire; HPLPII = Health Promoting Lifestyle Profile II. Presented values are means (and standard deviations) of raw scores obtained on the outcome measures. Higher scores are associated with better performance for each of the measures.

**Supplementary Table 4**

*Intention-to-Treat Analysis*

| | Group-by-time interaction | | | | Post-hoc tests | |
|---|---|---|---|---|---|---|
| | *F* | *df* | *p* | Partial $\eta^2$ | Post-test *d* | Follow-up *d* |
| Memory Knowledge Quiz | 20.96 | 1, 174 | < .01 | 0.108 | 0.68* | 0.51* |
| Memory Strategy Toolbox | 14.59 | 1, 200 | < .01 | 0.068 | 0.43* | 0.34* |
| MMQ Satisfaction | 4.25 | 1, 200 | .04 | 0.021 | 0.10 | 0.12 |
| MMQ Ability | 1.71 | 1, 200 | .19 | 0.008 | | |
| MMQ Strategy | 6.10 | 1, 200 | .014 | 0.030 | 0.33* | 0.28* |
| HPLPII | < 1 | 1, 200 | .55 | 0.002 | | |

*Note*. Group-by-time post-hoc analyses were performed separately for the post-test and follow-up periods, for those variables that showed a significant overall interaction. MMQ = Multifactorial Memory Questionnaire. HPLPII = Health Promoting Lifestyle Profile II.

* $p < .05$