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The Impact of Sustained Engagement on Cognitive Function in Older Adults: The Synapse Project

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Abstract

In the research reported here, we tested the hypothesis that sustained engagement in learning new skills that activated working memory, episodic memory, and reasoning over a period of 3 months would enhance cognitive function in older adults. In three conditions with high cognitive demands, participants learned to quilt, learned digital photography, or engaged in both activities for an average of 16.51 hr a week for 3 months. Results at posttest indicated that episodic memory was enhanced in these productive-engagement conditions relative to receptive-engagement conditions, in which participants either engaged in nonintellectual activities with a social group or performed low-demand cognitive tasks with no social contact. The findings suggest that sustained engagement in cognitively demanding, novel activities enhances memory function in older adulthood, but, somewhat surprisingly, we found limited cognitive benefits of sustained engagement in social activities.

Keywords

cognitive aging; intervention; engagement; cognitive training; aging cognition; episodic memory; cognitive reserve; working memory

Despite the tremendous strides made in scientifically based recommendations for promoting physical health in adulthood, less is known about what one should do to maintain cognitive health. As baby boomers age, the issue of maintaining healthy cognitive function has become a problem of increasing social urgency. There is a considerable amount of

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Author Contributions: D. C. Park developed the study concept and directed the project. J. Lodi-Smith managed the project for 2 years and conducted preliminary analyses. Testing and data collection were performed by G. N. Bischof and W. Aamodt. S. Haber and A. Hebrank analyzed and interpreted the data under the supervision of D. C. Park. S. Haber and D. C. Park drafted and edited the manuscript, and L. Drew and A. Hebrank provided critical revisions. All authors approved the final version of the manuscript for submission.

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correlational data suggesting that individuals who are engaged in intellectual and social activities in middle and late adulthood fare better cognitively than their less active peers. For example, self-reports of higher participation in cognitive, leisure, and social activities are related to better cognitive ability in middle-aged adults (Singh-Manoux, Richards, & Marmot, 2003) and are even associated with a decreased risk of being diagnosed with Alzheimer's disease (Wilson et al., 2002; Wilson, Scherr, Schneider, Li, & Bennett, 2007).

Such results are intriguing, but there is surprisingly little evidence that lifestyle engagement maintains or improves cognitive function (Hertzog, Kramer, Wilson, & Lindenberger, 2008). No doubt the reason is the difficulty of translating this hypothesis into an experimental design in which volunteers agree to be randomly assigned to conditions that significantly alter their daily experiences for a sustained period. Two studies to date have approached this issue. In one study, participants in the Senior Odyssey program engaged in diverse problem-solving activities in a group-based competition that spanned approximately 5 months and showed small but reliable improvements in speed of processing, inductive reasoning, and divergent thinking skills when compared with no-treatment control participants (Stine-Morrow, Parisi, Morrow, & Park, 2008). In another intervention project, older adults taking part in Experience Corps spent sustained periods partnered with elementary school students, teaching them literacy skills, library skills, and classroom etiquette over a prolonged period. When compared with a wait-list control group, these adults showed improvements in executive function and memory (Carlson et al., 2008). These findings are encouraging, but many questions about the impact of sustained engagement on cognitive function remain (for a review, see Stine-Morrow & Basak, 2011).

We examined the impact of sustained engagement on cognitive function in older adults using multiple control conditions, building on a distinction between *productive* engagement versus *receptive* engagement. These two types of engagement are differentiated by the cognitive operations they involve. Productive engagement refers to activities that require active learning and sustained activation of working memory, long-term memory, and other executive processes. In contrast, receptive engagement refers to activities that rely on passive observation, activation of existing knowledge, and familiar activities, rather than the acquisition of novel information and engagement in cognitively challenging tasks (Park, Gutchess, Meade, & Stine-Morrow, 2007). We created an environment called “Synapse” to investigate the hypothesis that productive engagement is more likely than receptive engagement to lead to improvements in cognition due to sustained activation of core cognitive abilities.

Although the cognitive-training literature suggests that older adults can achieve gains in processing speed, working memory, and episodic memory when they train a particular ability over a prolonged period (Ball et al., 2002), there is little evidence that the training transfers to other domains (although see Anguera et al., 2013; Basak, Boot, Voss, & Kramer, 2008). The Synapse Project differs from cognitive training in that subjects agree to make a lifestyle change and learn a new, real-world skill in a social environment that demands extended use of core cognitive abilities.

In the present study, participants were enrolled for 3 months in one of six lifestyle conditions, five of which required 15 hr of weekly engagement in structured activities. The three productive-engagement conditions were (a) the photo condition, in which novice participants learned digital-photography and computer skills using photo-editing software; (b) the quilt condition, in which novice participants learned how to design and sew quilts; and (c) the dual condition, in which participants spent half of the 3-month period engaged in quilting and the other half in photography.

These conditions involved continual learning of new and increasingly complex tasks over a prolonged period. Participants in the photo condition learned to operate a single-lens reflex camera (which they had to remember how to use when off-site) and also acquired considerable skill in complex software operations for photo editing and production. The manipulation was particularly demanding of executive function, long-term memory, and reasoning. In the quilt condition, participants learned to piece together and visualize abstract shapes to form complex, integrated patterns, in addition to learning the many operations associated with a software-driven sewing machine; hence, in this condition, there was a strong focus on visuospatial working memory and reasoning.

The receptive-engagement conditions were (a) the social condition, in which participants engaged in on-site, facilitator-led social interactions, field trips, and entertainment; and (b) the placebo condition, in which participants engaged in tasks at home that appeared to be beneficial to cognition but had no substantiated link to cognitive improvement (e.g., listening to classical music, completing word-meaning puzzles). Finally, the sixth condition, which did not require a 15-hr time commitment per week, was a no-treatment control condition.

We hypothesized that the participants assigned to the productive-engagement conditions would show improved cognition relative to those in the receptive-engagement conditions. Moreover, we expected that participants in the photo condition would show greater improvement in verbal memory, whereas those in the quilt condition would show more improvement in visuospatial abilities. The inclusion of the social condition provided information about whether socializing alone without formal learning can produce cognitive gains. Although the social condition had few formal cognitive demands, it did involve meeting new people and learning their names, so it was more cognitively demanding than the placebo and no-treatment conditions, but far less demanding than any of the productive conditions. The failure to include a social control group has been a serious limitation of previous lifestyle-engagement studies; including such a condition allowed us to determine the role that social interactions play in facilitation effects associated with engagement.

Method

Participants

A total of 259 participants were enrolled in the study, with 221 completing the full 14-week program (completion rate = 85%).¹ Participants ranged in age from 60 to 90 ($M = 71.67$ years); demographic information can be found in Table 1. Participants could be included in the study if they had at least a tenth-grade education, were fluent in English, worked or

performed volunteer activities for no more than 10 hr per week, were novices at both quilting and digital photography, and used a computer only for social networking and for less than 10 hr per week. Additional eligibility requirements included visual acuity (20/40 vision or corrected to 20/40 vision; Snellen, 1862), a minimum score of 26 on the Mini-Mental State Examination (Folstein, Robins, & Helzer, 1983), and no major psychiatric disorders.

Overview of study

Prior to the study, all prospective participants attended a detailed information session in which the six study conditions were described and the importance of random assignment was explained. The potential for cognitive improvement was emphasized in all conditions except for the no-treatment control condition. In an effort to ensure that participants would perform an activity of some interest to them, we allowed them to exclude one of the three productive-engagement conditions (photo, quilt, or dual) to which they could have been randomly assigned.

The productive-engagement groups met over a 14-week period in a project-specific space (which we called the “Synapse Center”) located in a strip mall in Dallas, Texas. The Synapse Center was a learning environment that was available to participants 35 hr per week and included two large activity spaces for quilting and photography and a large area for socializing. We had the three remaining groups (social, placebo, no treatment) meet at a different Synapse site 1.5 miles away to prevent interactions between productive- and receptive-engagement participants. Data collection took place in five waves of assessment between August 2008 and May 2011. All data remained sealed until the last participant was assessed, and no data were analyzed until the study was finished.

Productive-engagement conditions

Participants assigned to the productive-engagement conditions were directed to spend an average of 15 hr per week in the Synapse environment: 5 hr of formal instruction and 10 hr completing course assignments. Participants received instruction in groups of six. The three engagement conditions are described in the following sections.

Photo condition—Participants were instructed by a professional photographer who trained them to use cameras and develop computer skills required to use professional photography software for photo editing. This condition was particularly demanding of episodic verbal memory and reasoning, given that participants had to remember many complex verbal instructions to use both the software and camera. On average, participants spent 15.84 hr ($SD = 1.95$) per week working on projects.

¹Thirty-eight participants were excluded or dropped from the study. Of these, 22 were dropped or excluded for reasons unrelated to the condition to which they were assigned (e.g., illness, family problems). Attrition of the remaining 16 participants could conceivably have been related to condition (e.g., stated disinterest, concern about the time commitment). Of these 16 participants, 5 were in the photo condition, 2 were in the quilt condition, 2 were in the dual condition, 5 were in the social condition, and 2 were in the no-treatment condition. We found no statistical or even anecdotal evidence that differences were due to condition assignment.

Quilt condition—The quilt condition had the same format as the photo condition and was under the direction of a professional quilting instructor. All participants learned basic skills and progressed to complete complex, individual projects using computer-driven sewing machines. On average, participants who completed the program spent 15.93 hr ($SD = 2.55$) working on projects per week.

Dual condition—The dual condition included training in both digital photography and quilting for 6.5 weeks each; in the final week of the study, participants could complete projects in either class. The order of the two types of training was counterbalanced across participants. The instructors were the same as in the photo and quilt conditions. This condition had more breadth of stimulation but less depth in each particular domain. On average, participants spent 18.11 hr ($SD = 4.48$) working on projects each week.

Control conditions

Social condition—The social condition mimicked a social club: It involved instructor-directed activities, such as cooking, playing games, watching movies, reminiscing, and going on regular field trips organized around a different topic, such as travel or history, each week. The social-group curriculum relied as much as possible on participants' existing knowledge, with no formal knowledge acquisition. Games could be won largely by chance, with low requirements for strategy. The social activities involved no active skill acquisition. As in the productive-engagement conditions, participants in the social condition were directed to complete 5 hr of common structured activities and 10 hr or more of additional activities on-site with other group members each week. The social-condition participants spent an average of 15.90 hr ($SD = 1.63$) on social activities each week.

Placebo condition—For 15 hr per week, participants performed a structured set of activities that relied on activation of existing knowledge or activities that have not been reliably linked by empirical evidence to cognitive improvement but are commonly thought of as being cognitively engaging. Each week, participants were provided with an assigned packet of materials for 5 hours' worth of activities (i.e., documentaries, informative magazines such as *National Geographic*, word games relying on knowledge, and classical-music CDs) and were asked to select at least 10 hr of additional activities from the “Brain Library” (a collection of magazines, DVDs, CDs, and crossword puzzles). Participants recorded the time they spent on the activities and visited the site for a few minutes at a scheduled time each week to pick up and drop off weekly assignments. Participants spent an average of 17.22 hr ($SD = 2.50$) on these activities each week.

No-treatment condition—Participants in the no-treatment condition were required only to complete a weekly checklist of their daily activities, which was dropped off at the research site at a scheduled time each week.

Cognitive battery

Each participant completed a battery of pre- and postintervention cognitive tests and psychosocial questionnaires. Testers were blind to condition assignment and were not involved in the intervention. Testing included both paper-and-pencil and computerized

tasks. The cognitive constructs assessed and the tasks associated with the constructs were as follows:

- Processing speed, assessed using digit-comparison tasks with three, six, and nine items (Salthouse & Babcock, 1991).
- Mental control, assessed using Flanker Center Letter, Flanker Center Arrow, and Flanker Center Symbol tasks (modified from Eriksen & Eriksen, 1974) and the Cogstate Identification Task (<http://www.cogstate.com>).
- Episodic memory, assessed using the immediate-recall section of the modified Hopkins Verbal Learning Task (Brandt, 1991), the Cambridge Neuropsychological Test Automated Battery (CANTAB) Verbal Recognition Memory Task (Robbins et al., 1994), and the long-delay section of the modified Hopkins Verbal Learning Task (Brandt, 1991).
- Visuospatial processing, assessed using the CANTAB Spatial Memory Task, the CANTAB Stockings of Cambridge Task, and a modified version of Raven's Progressive Matrices (Raven, 1976).

Analysis and Results

We modeled our analysis after that used for the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) trial, the largest cognitive intervention reported to date (Ball et al., 2002). We standardized the scores for each cognitive measure by pooling the two scores (pretest and posttest) for each participant across all experimental conditions and applying an inverse-normal transformation on rank-ordered scores in this pool using a weighting suggested by Blom (1958). The normalized task scores for the pretest and posttest were then adjusted to the means and standard deviations of pretest scores (Ball et al., 2002). We note that gender had no significant effects when included in reported analyses.

Cognitive constructs

We conducted an exploratory factor analysis using an oblimin rotation on the pretest normalized scores for each cognitive measure described above, which resulted in a clear four-factor structure, $\chi^2(41, N = 221) = 67.0, p < .01$. We found measurement invariance across conditions, and the same structure fit the posttest data. Given the clear factor structure and its match to a priori theoretical constructs, we accepted the factors (processing speed, mental control, episodic memory, and visuospatial processing). The normalized scores associated with each construct were averaged to produce one factor score per individual for each testing session. Missing test scores were not imputed. Each construct was reliable, as was test-retest reliability. We note that the no-treatment control condition was included so that we could calculate test-retest reliability, but this group was not included in any further analyses (Nunnally, 1978). We also found that across conditions, participants did not differ in their initial performance on any of the cognitive constructs, and that, despite the restricted range of ages (60–90), there was significant age-related cognitive decline on all of the tasks (Horn & Cattell, 1967; Park et al., 2002). Table 2 presents these data.

Cognitive-intervention analyses

Productive versus receptive engagement—To test the hypothesis that productive engagement was more facilitative of cognition than was receptive engagement, we contrasted the three productive-engagement conditions (quilt, photo, and dual) with the two receptive-engagement conditions (social and placebo). A 2×2 analysis of variance (ANOVA) was conducted with condition (productive vs. receptive) as the between-subjects variable and time (pretest vs. posttest) as the within-subjects factor on each cognitive construct. We observed a significant Condition \times Time interaction for episodic memory, $F(1, 179) = 9.63, p = .002$, which occurred because the productive-engagement groups improved significantly more over time than did the receptive-engagement groups (see Fig. 1). Post hoc analyses of the episodic-memory interaction showed there was no significant difference between the two receptive-engagement conditions ($p = .59$), nor did the three productive-engagement conditions differ from one another ($p = .19$). Significant Condition \times Time interaction effects were not present for processing speed, mental control, or visuospatial processing. We also specifically tested the hypothesis that productive engagement was more facilitative of cognition than social engagement and found that the productive-engagement groups improved more than the social group from pretest to posttest, $F(1, 140) = 4.40, p < .04$.

Specific effects of intervention—The pretest and post-test transformed scores for each condition and cognitive domain are presented in Table S2. To determine the effects of different types of productive engagement, we compared each productive-engagement condition with the placebo condition. Thus, for example, for the analysis comparing the photo and placebo conditions, a 2×2 repeated measures ANOVA was conducted with condition (photo vs. placebo) as the between-subjects variable and Time (pretest vs. posttest) as the within-subjects variable for each cognitive construct. In this analysis, we found a significant Condition \times Time interaction for episodic memory, $F(1, 66) = 11.09, p = .01$, with a net effect size of .54.² We also found a marginally significant interaction for visuospatial processing, $F(1, 66) = 3.43, p = .07$, with an effect size of .28, due to greater improvement in the photo condition. The analysis comparing the dual and placebo conditions also yielded a Condition \times Time interaction for episodic memory, a result due to greater improvement in the dual condition, $F(1, 79) = 3.83, p = .05$, with a net effect size of .22. We also observed a Condition \times Time interaction for processing speed in this analysis, $F(1, 79) = 3.10, p = .05$, with a net effect size of .29. No significant effects were observed in the comparison of the quilt and placebo conditions.

Figure 2 presents gain scores for episodic memory (standardized posttest scores minus pretest scores) as a function of condition for all of the cognitive domains. We note that when the comparisons shown in Figure 2 were corrected with a Bonferroni-Holm correction

²Net effect size of intervention was calculated using the following formula:
$$\frac{(B_i^{\text{post}} - B_p^{\text{post}}) - (B_i^{\text{pre}} - B_p^{\text{pre}})}{s^{\text{pre}}}$$
, where s^{pre} is the standard deviation at pretest, B_i^{pre} and B_i^{post} represent pre- and post-Blom transformation scores for the intervention conditions, and B_p^{pre} and B_p^{post} represent pre- and post-Blom transformation scores for the placebo condition.

(Holm, 1979) for multiple comparisons, the only significant interaction that remained was the episodic memory effect observed in the photo-versus-placebo comparison. We also assessed whether learning photography skills was more facilitative of cognition than socializing alone by comparing the photo condition with the social condition (rather than the placebo condition), and found that the episodic-memory effect remained significant, $F(1, 63) = 8.70, p = .01$.

To further explicate the intervention effect on episodic memory at the individual level, we present percent reliable change (Ball et al., 2002),³ defined as improvement on the posttest relative to the pretest that was greater than 1 standard error of measurement, for each participant in the five intervention conditions (Fig. 3). Figure 3 demonstrates that the proportion of participants showing reliable improvement in the photo, quilt, and dual conditions was .76, .60, and .57, respectively. The social and placebo groups improved less, with the proportions of participants showing improvements at .47 and .46, respectively.

Discussion

The present study represents a serious attempt to change everyday lifestyles in older adults for a period of 3 months and ascertain the impact of different types of lifestyle changes on cognitive function in an elderly sample. Three of the conditions involved productive engagement, that is, participants learned novel and demanding new skills for 15 hr or more per week over the 3-month period. These conditions were contrasted with a receptive-engagement condition (the social control condition) in which participants engaged in novel activities and socialized for 15 hr a week but did not actively acquire new skills. This manipulation allowed us to dissociate the impact of socializing and other novel aspects of the situation in the social condition from active skill and knowledge acquisition. This important condition has been omitted from past intervention studies that examined the impact of engagement on cognition. Additionally, the inclusion of a placebo condition, in which participants had limited social interactions and worked alone on tasks that they believed would improve cognition, provided an appropriate baseline against which to assess the impact of the other interventions.

The results can be summarized as follows. First, we found that productive engagement (in the quilt, photo, and dual conditions) caused a significant increase in episodic memory compared with receptive engagement (in the social and placebo conditions). A further comparison demonstrated that the three productive-engagement groups were superior in episodic memory when compared with the social group alone. Thus, we found evidence that sustained effort to acquire a demanding new skill improved episodic memory and no evidence suggesting that socializing, information exchange, and novelty alone facilitated cognitive function. Second, our more fine-grained analyses of specific conditions showed that participants in the photo and dual conditions exhibited a significant improvement in episodic memory, whereas the effect was not significant for those in the quilt condition (p

³Percent reliable change was calculated using the following formula: $\frac{B_i^{\text{post}} - B_i^{\text{pre}}}{s^{\text{pre}}} \geq s^{\text{pre}} \sqrt{1 - R}$, where R is the test-retest reliability of the each measure that was obtained from the no-treatment control condition.

= .11) but was in the direction of facilitation. We also found some evidence that participants in the photo condition showed an improvement in visuospatial processing and that those in the dual condition improved their processing speed.

Overall, the results suggested that learning digital photography, either alone or in combination with learning to quilt, had the most beneficial effect on cognition, and that the positive impact was primarily on memory function. We note that the photo condition was considerably more demanding of episodic memory, and this may explain its greater facilitative impact relative to quilting: In the photo condition, there was a great deal of information presented to novice users of computers and cameras regarding complex photographic software, whereas the quilt condition had a somewhat stronger procedural component after the initial skill-acquisition period. The finding of improved episodic memory as a function of engagement without direct memory training is similar to that reported for the Experience Corps trial, in which participants worked with school children over the course of an academic year (Carlson et al., 2008), and is also similar to findings from a study in which older adults showed episodic-memory improvement as a result of theatrical training (Noice, Noice, & Staines, 2004).

A question that emerges is why episodic memory seems more sensitive to improvement than other cognitive abilities. One possibility is that of the abilities measured, episodic memory is the most strategic and the most reliant on use of existing knowledge, given that there is clear evidence that self-imposed organizational strategies enhance memory (for a review, see Verhaeghen, Marcoen, & Goossens, 1992). Perhaps sustained participation in engaging activities facilitated strategic, organizational behaviors. A second alternative is that the facilitation in memory occurred because engagement enhanced attentional capabilities and freed cognitive resources for encoding and retrieval. We believe the strategy hypothesis is more likely, because an increase in attentional resources should have resulted in broad improvements across all measured abilities. Neuroimaging data could provide definitive information about how underlying networks changed with the intervention and could greatly enhance our understanding of the underlying causal mechanisms.

Another possible interpretation of the observed effects is that because participants in the productive-engagement groups mastered specific skills, they had stronger beliefs that the intervention was improving their memory, which in turn enhanced their performance compared with that of participants in the placebo and social conditions. This seems unlikely. We examined participants' performance on the Metamemory in Adulthood Questionnaire (Dixon & Hultsch, 1984), which included a subscale for self-rated memory capacity. If there were differences between conditions regarding the perceived effectiveness of the assigned intervention, there would have been a disproportional change in perceived memory capacity across conditions. Importantly, we found no significant differences across conditions in either pretest perceived memory capacity ($p = .23$) or changes in perceived memory capacity at post-test ($p = .69$). We also found no differences between the productive- and receptive-engagement groups in other psychosocial measures such as well-being and depression. Finally, the productive- and receptive-engagement groups were run at separate sites to minimize participants' exposure to the differences in the challenges faced by productive versus receptive groups.

To summarize, the present study is perhaps the most systematic and complete study of the impact of engagement in novel, cognitively challenging activities on cognition in older adults. We recognize that the findings yield at least as many questions as answers. Nevertheless, the research provides clear evidence that memory function is improved by engagement in demanding everyday tasks. We found no cognitive benefit of social engagement, a confounding variable in most previous studies. Nevertheless, we believe more work needs to be done on social engagement before this finding is viewed as definitive. This research is particularly important because, unlike computer training, productive engagement has the potential to be self-reinforcing and propagate continued learning and intellectual stimulation. Long-term follow-up will be crucial in determining whether facilitation effects are maintained or even enhanced over time. The present results provide some of the first experimental evidence that learning new things and keeping the mind engaged may be an important key to successful cognitive aging, just as folk wisdom and our own intuitions suggest.

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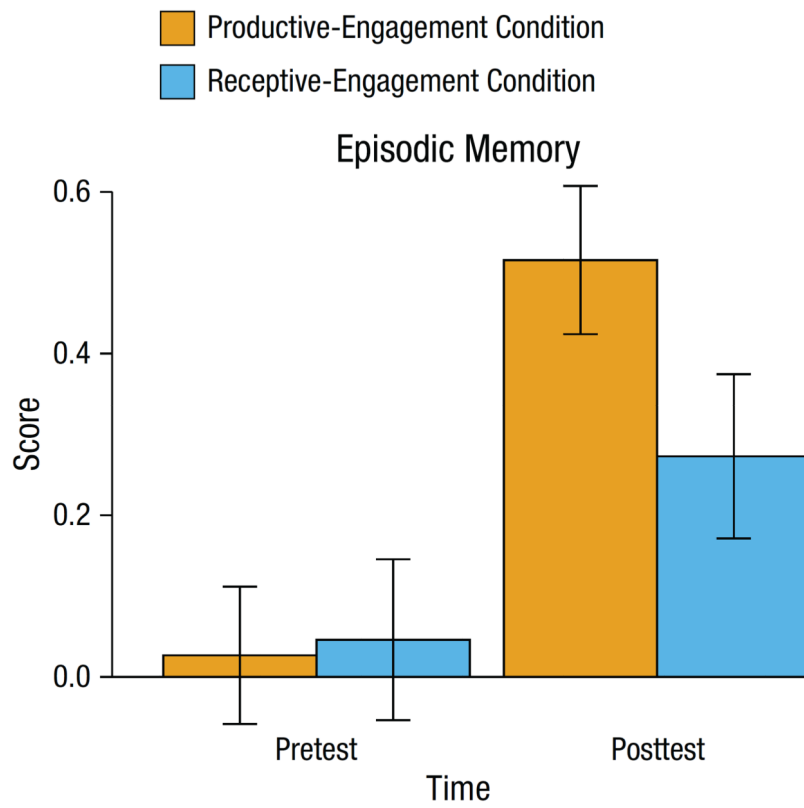


Fig. 1. Normalized mean score for episodic memory as a function of condition and time. Error bars represent $\pm 1 SE$.

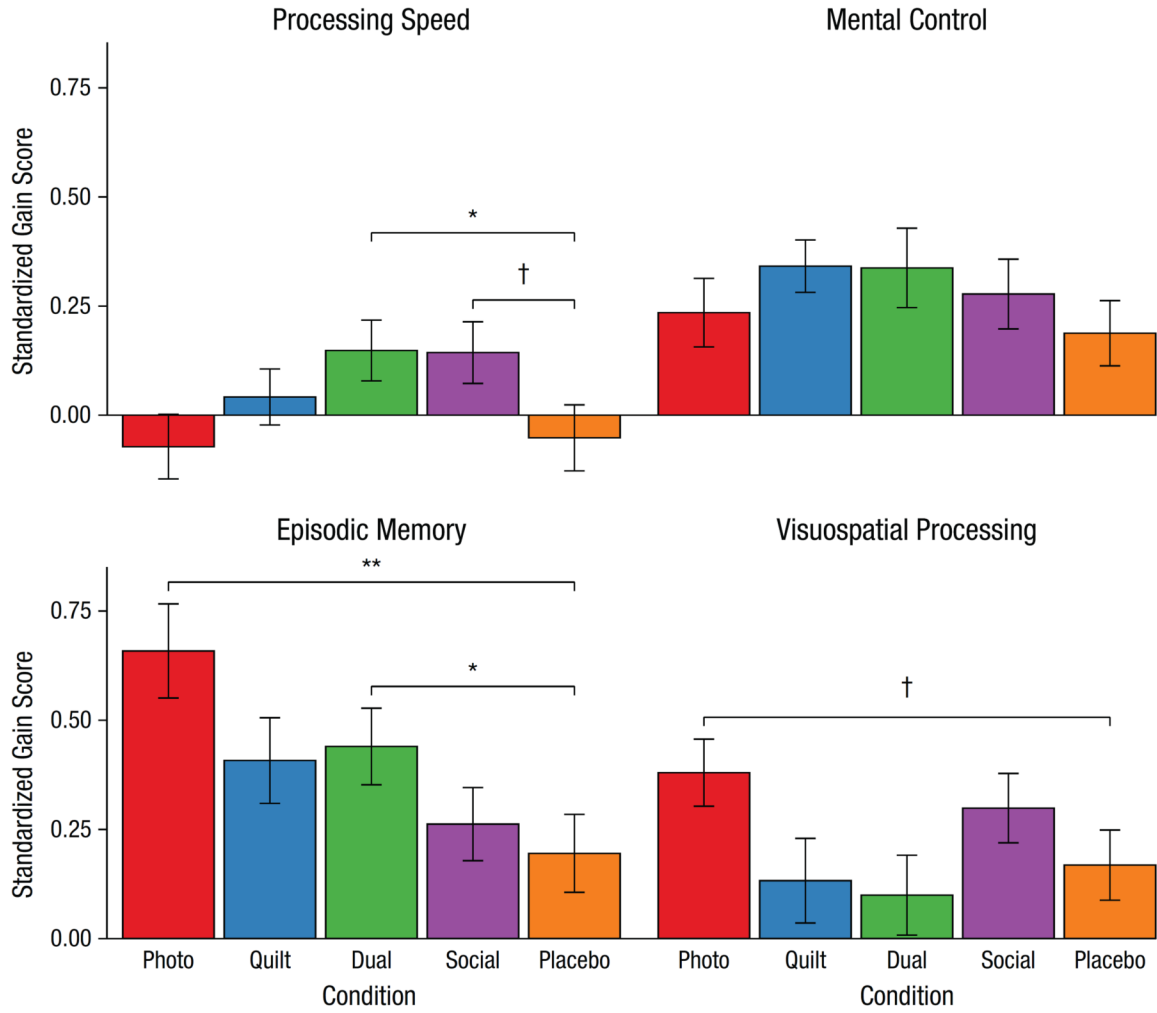


Fig. 2. Mean standardized gain score as a function of condition for each cognitive construct. The standardized scores from the posttest were subtracted from standardized scores from the pretest, yielding the mean standardized gain scores for each cognitive construct. Error bars represent $\pm 1 SE$. Asterisks represent significant differences between conditions ($*p = .05$; $**p = .01$); daggers represent marginally significant differences between conditions ($p = .10$).

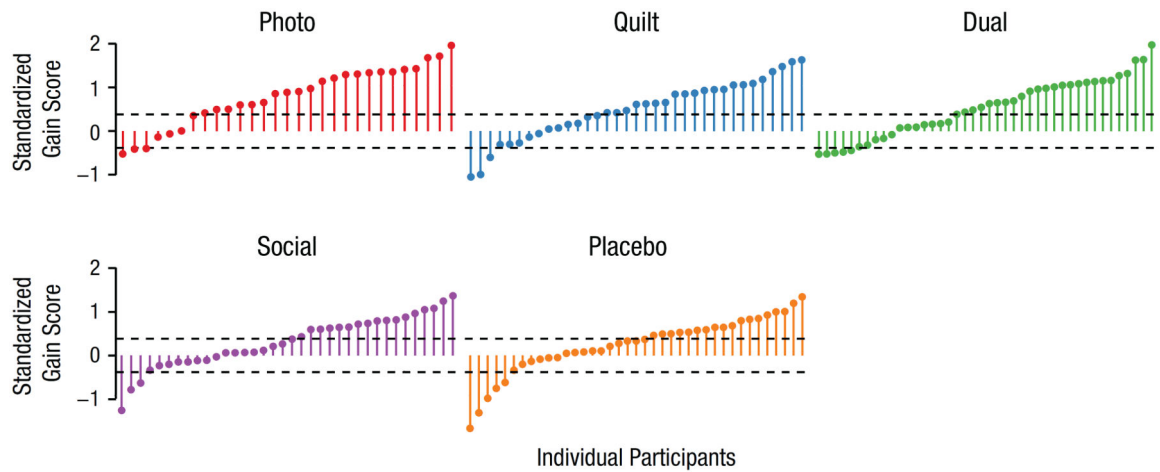


Fig. 3. Standardized gain score for episodic memory for each participant. Results are shown separately for each condition. The dashed horizontal lines represent the standard error of measurement (the upper line is $+1 SEM$, and the lower line is $-1 SEM$). Vertical lines above the dashed horizontal line represent a reliable positive change in performance, and vertical lines below the dashed line indicate a reliable negative change in performance.

Table 1
Demographic Information for Participants in All Conditions

Condition	Mean age in years	Mean years of education	Female participants (%)	Minority participants (%)
All conditions (<i>N</i> = 221)	71.67 (7.29)	16.02 (3.06)	73.9	14.2
Photo (<i>n</i> = 29)	72.83 (6.70)	16.16 (3.10)	65.5	6.5
Quilt (<i>n</i> = 35)	71.69 (6.67)	15.54 (2.34)	74.3	13.5
Dual (<i>n</i> = 42)	69.74 (7.00)	16.92 (3.00)	64.3	11.9
Social (<i>n</i> = 36)	72.14 (8.06)	16.58 (2.97)	86.1	16.2
Placebo (<i>n</i> = 39)	70.97 (7.12)	15.79 (2.76)	84.6	20.5
No treatment (<i>n</i> = 40)	73.08 (7.87)	15.41 (3.53)	72.5	15.4
Significance of group effect	<i>p</i> = .34	<i>p</i> = .17	<i>p</i> = .14	<i>p</i> = .34

Note: Standard deviations are shown in parentheses.

Table 2
Age Correlations and Reliability for Cognitive Constructs

Cognitive construct and measure	Dependent variable	Correlation with age	Composite reliability (Cronbach's α)	Test-retest reliability
Processing speed			.88	.87
Digit comparison: three-item trials	Total items correct	-.31**	—	—
Digit comparison: six-item trials	Total items correct	-.25**	—	—
Digit comparison: nine-item trials	Total items correct	-.23**	—	—
Mental control			.83	.80
Cogstate Identification ^a	Log RT to a two-alternative forced-choice decision	.23**	—	—
Flanker Center Letter ^a	RT for incongruent trials following congruent trials	.19**	—	—
Flanker Center Symbol ^a	RT for incongruent trials following congruent trials	.22**	—	—
Flanker Center Arrow ^a	RT for incongruent trials following congruent trials	.17**	—	—
Episodic memory			.83	.80
CANTAB Verbal Recall Memory	Total items correct on verbal free recall	-.23**	—	—
Hopkins Verbal Learning Task (Immediate)	Total items correct on Trials 1, 2, and 3	-.22**	—	—
Hopkins Verbal Learning Task (Delayed)	Total items correct on Trials 1, 2, and 3 after a 20-min delay	-.20**	—	—
Visuospatial processing			.77	.61
CANTAB Stockings of Cambridge	Problems solved in the minimum number of moves	-.16*	—	—
Modified Raven's Progressive Matrices	Correct items (out of 18)	-.13*	—	—
CANTAB Spatial Working Memory ^a	Times a box where a token had previously been found was revisited	.29**	—	—
CANTAB Spatial Working Memory ^a	Number of times a new search was begun with the same box	.15*	—	—

Note: Test-retest reliabilities were calculated from the no-treatment condition. The digit-comparison tasks were drawn from Salthouse and Babcock (1991); the Cogstate Identification Task was drawn from <http://www.cogstate.com>; the flanker tasks were drawn from Eriksen and Eriksen (1974); the Cambridge Neuropsychological Test Automated Battery (CANTAB) tasks were drawn from Robbins et al. (1994); the Hopkins Verbal Learning Task measures were drawn from Brandt (1991); and the modified version of Raven's Progressive Matrices was based on Raven (1976). RT = response time.

^aFor these tests, an age-associated decline in performance is represented by a positive correlation.

* $p = .05$.

** $p = .001$.