Long-term Effects of Cognitive Training on Everyday Functional Outcomes in Older Adults

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Context Cognitive training has been shown to improve cognitive abilities in older adults but the effects of cognitive training on everyday function have not been demonstrated.

Objective To determine the effects of cognitive training on daily function and durability of training on cognitive abilities.

Design, Setting, and Participants Five-year follow-up of a randomized controlled single-blind trial with 4 treatment groups. A volunteer sample of 2832 persons (mean age, 73.6 years; 26% black), living independently in 6 US cities, was recruited from senior housing, community centers, and hospitals and clinics. The study was conducted between April 1998 and December 2004. Five-year follow-up was completed in 67% of the sample.

Interventions Ten-session training for memory (verbal episodic memory), reasoning (inductive reasoning), or speed of processing (visual search and identification); 4-session booster training at 11 and 35 months after training in a random sample of those who completed training.

Main Outcome Measures Self-reported and performance-based measures of daily function and cognitive abilities.

Results The reasoning group reported significantly less difficulty in the instrumental activities of daily living (IADL) than the control group (effect size, 0.29; 99% confidence interval [CI], 0.03-0.55). Neither speed of processing training (effect size, 0.26; 99% CI, −0.002 to 0.51) nor memory training (effect size, 0.20; 99% CI, −0.06 to 0.46) had a significant effect on IADL. The booster training for the speed of processing group, but not for the other 2 groups, showed a significant effect on the performance-based functional measure of everyday speed of processing (effect size, 0.30; 99% CI, 0.08-0.52). No booster effects were seen for any of the groups for everyday problem-solving or self-reported difficulty in IADL. Each intervention maintained effects on its specific targeted cognitive ability through 5 years (memory: effect size, 0.23 [99% CI, 0.11-0.35]; reasoning: effect size, 0.26 [99% CI, 0.17-0.35]; speed of processing: effect size, 0.76 [99% CI, 0.62-0.90]). Booster training produced additional improvement with the reasoning intervention for reasoning performance (effect size, 0.28; 99% CI, 0.12-0.43) and the speed of processing intervention for speed of processing performance (effect size, 0.85; 99% CI, 0.61-1.09).

Conclusions Reasoning training resulted in less functional decline in self-reported IADL. Compared with the control group, cognitive training resulted in improved cognitive abilities specific to the abilities trained that continued 5 years after the initiation of the intervention.

Trial Registration clinicaltrials.gov Identifier: NCT00298558

JAMA. 2006;296:2805-2814 www.jama.com

DECLINE IN COGNITIVE ABILITIES has been shown to lead to an increased risk of difficulty in performing instrumental activities of daily living (IADL).[1-5] However, whether interventions to maintain or enhance cognitive abilities in older adults will prevent or delay these functional difficulties is unclear. Prior interventions with older adults have targeted those with cognitive deficits or functional disabilities and have focused on remediation rather than prevention.[6,7] Prior studies have shown that cognitive interventions can improve cognitive abilities in normal elders but have not included functional outcome measures and have been limited by small, homogeneous samples and lack of randomization.[8-11]

For editorial comment see p 2852.

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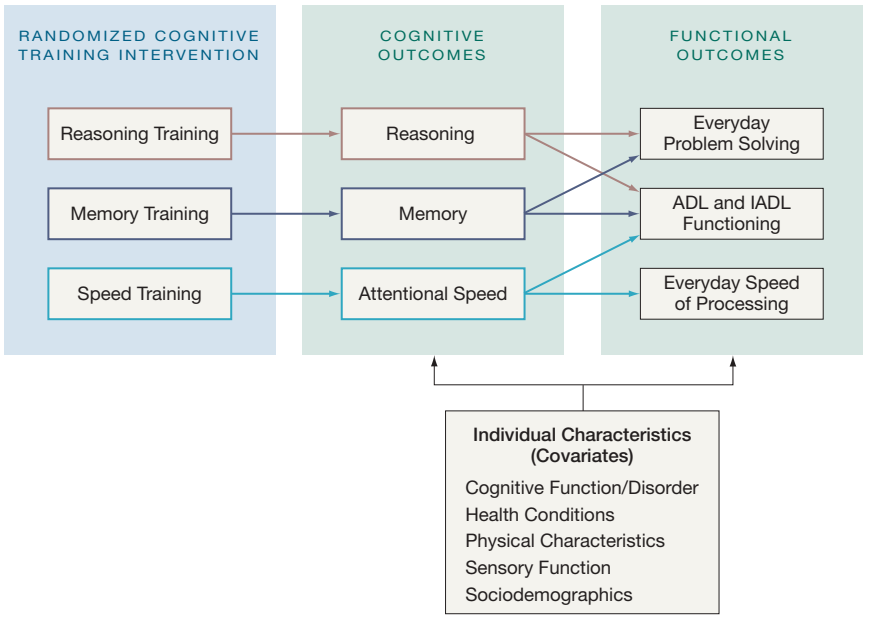
Figure 1. Conceptual Model of ACTIVE Trial



ACTIVE indicates Advanced Cognitive Training for Independent and Vital Elderly; ADL, activities of daily living; IADL, instrumental activities of daily living.

The Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study is the first multicenter, randomized controlled trial to examine the long-term outcomes of cognitive interventions on the daily functioning of older individuals living independently.[12] Previously reported data from the ACTIVE study showed that each of 3 cognitive interventions improved the cognitive ability it targeted and these improvements were maintained through the 2 years of follow-up.[13] This article addresses the long-term effects of cognitive training on the maintenance of self-reported IADL.

FIGURE 1 presents the conceptual model for the ACTIVE trial. Four hypotheses were derived from this model. First, cognitive training would affect the cognitive ability targeted by that training and these effects would be maintained over time. Second, maintained improvements in cognitive ability would have a positive transfer effect on everyday function. Based on prior research,[14,15] we expected to first see this transfer of training effects to affect IADL functioning. Third, this training transfer from cognitive abilities to IADL function would occur in all 3 training groups because each of the 3 cognitive abilities has been associated with IADL functioning.[9,16] While the broadest transfer of training effects was expected to improve IADL functioning, we also expected to see other training-specific effects (ie, transfer of improvement in reasoning and memory to improvements in everyday problem solving or transfer of improvement in speed of processing to improvements in everyday speed of processing tasks). Finally, because of the functional independence of participants at baseline, it was hypothesized that observations of training effects on IADL functioning would be delayed until the control group began to experience significant functional decline. This was observed at the 5-year follow-up and therefore the hypothesized delayed outcome of maintenance of IADL function could be tested.

METHODS

Participants

The sample consisted of older adults living independently with good functional and cognitive status who were recruited from senior housing, community centers, and hospitals and clinics in Birmingham, Ala; Detroit, Mich; Boston, Mass; Baltimore, Md; Indianapolis, Ind; and State College, Pa. Participants were enrolled in the study between March 1998 and October 1999.[12] Persons were excluded if they were younger than 65 years; had substantial functional impairment (≥2 ADL disabilities) or cognitive decline (Mini-Mental State Examination [MMSE] score ≤22)[17]; self-reported diagnosis of Alzheimer disease; medical conditions associated with imminent functional decline or death; severe losses in vision, hearing, or communicative ability that would interfere with study participation; recent cognitive training; or were unavailable during the study period. Because previous studies of cognitive training had been conducted in white older adults, recruitment of other race and ethnic groups was emphasized. Race was self-reported as white, black, Asian, Native Hawaiian/Pacific Islander, American Indian/Alaskan Native, or biracial. Participants indicated if they were Hispanic or Latino.

Study Design

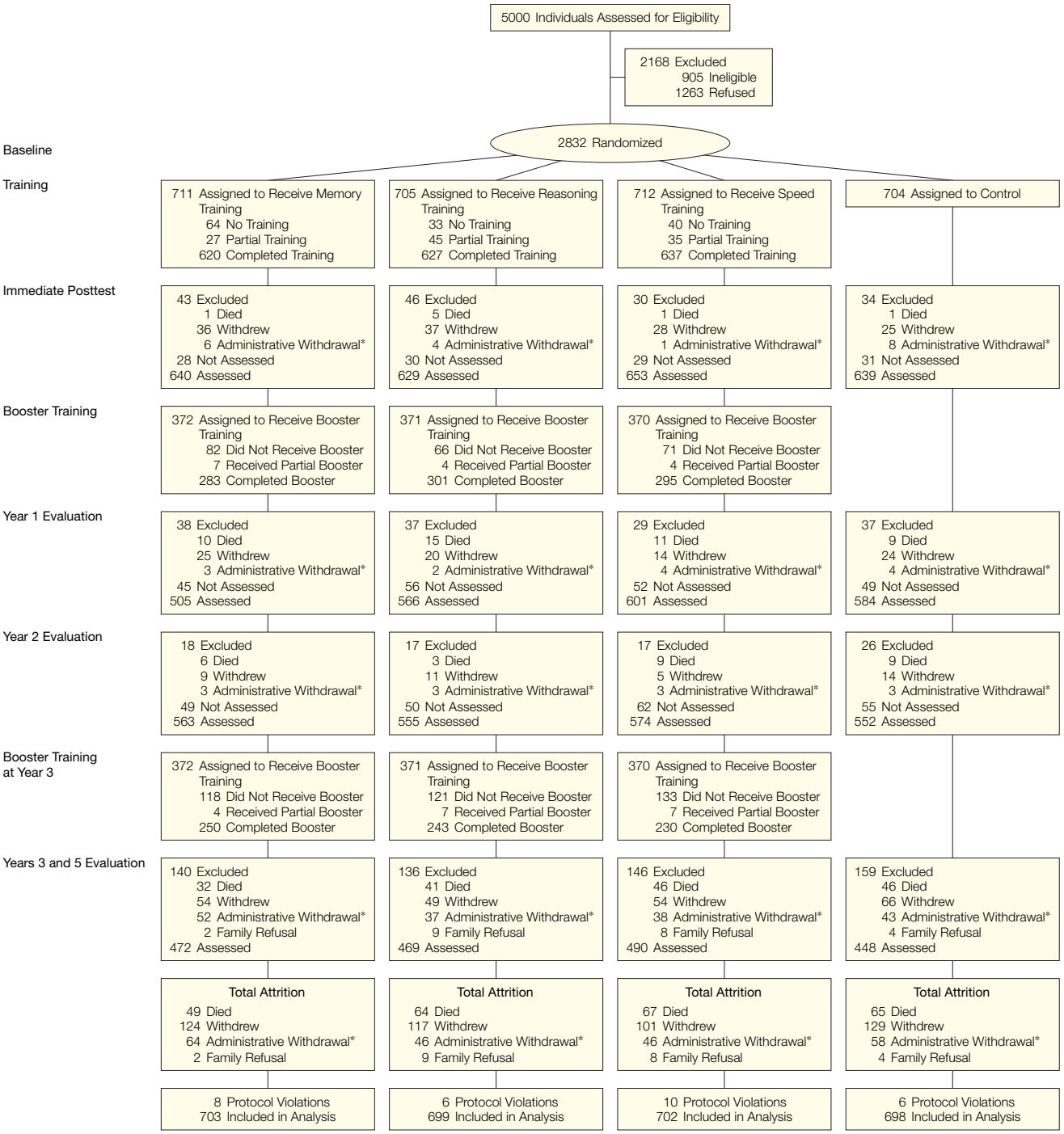
ACTIVE was a randomized controlled, single-blind trial, using a 4-group design, including 3 treatment groups and a control group (FIGURE 2). Participants were randomized to a group by the data coordinating center using a computer randomization program. Assessments were conducted at baseline, following the intervention, and annually at 1, 2, 3, and 5 years. Assessors were blinded to treatment assignment. Exposure to social contact was equated in the 3 intervention groups. The control group had no contact; a placebo social contact control was not included because prior intervention studies indicated no differences between a social contact control and a "no contact" control in either cognitive or functional improvement.[18,19] Prior ACTIVE results[13] showed that cognitive effects were specific to each intervention. The study protocol was approved by the institutional review boards at all sites and the trial was monitored by a data and

safety monitoring board. Written informed consent was obtained from all participants.

Interventions

Each of the 3 training interventions was designed to narrowly target a specific cognitive ability—memory, reasoning, or speed of processing—and included no overlap with the functional

Figure 2. Flow of Individuals in ACTIVE Trial



ACTIVE indicates Advanced Cognitive Training for Independent and Vital Elderly.
*Site-level decision was made to withdraw individual from the study.

outcomes in this study.[12,13] Memory training involved teaching mnemonic strategies (organization, visualization, association) for remembering verbal material (eg, word lists, texts).[8,20] Reasoning training involved teaching strategies for finding the pattern in a letter or word series (eg, a c e g i . . .) and identifying the next item in the series.[9,21] Speed of processing training involved visual search and divided attention (identifying an object on a computer screen at increasingly brief exposures followed by dividing attention between 2 search tasks).[16,22,23] Each training intervention was 10 sessions. Only 10% of the 60- to 75-minute training sessions focused on applying these strategies to solving everyday problems (eg, mnemonic strategies to remember a grocery list; reasoning strategies to understand the pattern in a bus schedule).

Booster training was conducted at 11 and 35 months after the initial training sessions and involved four 75-minute sessions. The goal of the booster sessions was to maintain the improvement in cognitive ability and the content of these sessions was similar to the training sessions, again focusing on strategies related to the cognitive abilities not on functional outcomes. Participants who completed the initial training were eligible for booster training.[12,13] A subsample of eligible participants was selected for booster training using a random number computer program. Given this selection contingency, participants who were selected and agreed to booster training were younger ($P=.007$) and had higher baseline cognitive function as evidenced by MMSE scores ($P=.008$) compared with participants who were eligible and not assigned to booster training and participants who were not eligible for booster training. Sixty percent of selected participants completed booster training at year 1 and year 3; 19% completed year 1 booster only, 6% completed year 3 booster only; and 15% did not complete any booster training. The last booster sessions were completed 2 years prior to the 5-year follow-up.

Outcome Measures

Cognitive outcomes were used to assess cognitive training effects and functional outcomes were used to assess the impact of improved cognitive abilities on instrumental functioning (see Jobe et al[12] for a detailed description).

Cognitive outcomes assessed the effects of each intervention on the cognitive ability trained. Memory training outcomes involved 3 measures of verbal memory ability: Hopkins Verbal Learning Test, Rey Auditory-Verbal Learning Test, and the Rivermead Behavioral Paragraph Recall test.[24-26] Reasoning training outcomes involved 3 reasoning ability measures: letter series, letter sets, and word series.[27-29] Speed of processing training outcomes involved 3 useful field of view subscales.[30-32]

Functional outcomes assessed whether the cognitive interventions had an effect on daily function. Everyday functioning represented the participant's self-ratings of difficulty (IADL difficulty from the Minimum Data Set–Home Care[33] and ranged from "independent" to "total dependence" on a 6-point scale) in completing cognitively demanding tasks involved in meal preparation, housework, finances, health maintenance, telephone use, and shopping. Two performance-based categories of daily function were also assessed. Everyday problem solving[34] assessed ability to reason and comprehend information in common everyday tasks (eg, identifying information in medication labels). Performance was measured with printed materials (eg, yellow pages, using the Everyday Problems Test[34]) and behavioral simulations (eg, making change, using the Observed Tasks of Daily Living[35]). These measures were hypothesized to be most closely related to reasoning and memory abilities due to their task demands. Everyday speed of processing assessed participants' speed in interacting with real-world stimuli (eg, looking up a telephone number, using the Timed IADL Test[36]), and the ability to react quickly to 1 of 4 road signs (Complex Reaction Time Test[22]), which was hypothesized to be the most closely related to speed of processing.

Because most outcomes were assessed by multiple measures, composite scores were formed by data reduction. Each measure was standardized to its baseline values and then an average of the equally weighted standardized scores was calculated. These composite scores permitted inferences about training effects at the level of outcome rather than at the level of a single test. The composite scores were consequently more reliable than single measures and also reduced the number of outcome analyses needed, reducing the overall type I error rate.

Analysis

To evaluate the effects of ACTIVE training, a repeated-measures, mixed-effects model[37] was used, including all assigned participants (for both initial training and booster training) consistent with the intention-to-treat principle. The dependent variables were the cognitive and functional outcomes at baseline and at 5-year follow-up. The scores for each test were transformed using the Blom transformation.[38,39] This transformation standardized the components in each domain to have equal weight and reduced skewness in the measures.

Independent variables were restricted to basic design features: fixed effects for treatment group, time, assignment to booster training, field site, and replicate within a site. Interaction terms were chosen for importance and interpretability: time × training, representing the net effect of the trial; booster × training, representing nonspecific effects of attending booster training regardless of content; time × booster × training, representing training-specific effects of each booster intervention; and replicate within a site, representing variation between and within field sites. Because there were no significant baseline differences in cognition and function across groups, these interaction terms capture the divergence across groups that can be attributed to the training interventions. Because participants who were assigned to booster training were younger and had higher baseline cognitive function, the

model comparing booster and nonbooster participants was then repeated controlling for baseline age and MMSE score. The models were fitted to the available data, ignoring missing data. To determine if selective attrition influenced the trial results, missing data were imputed using multiple imputation procedures.[40] The analysis was repeated and there were no differences in the results; therefore, the data presented do not include imputed values. All data analysis was conducted by statisticians at the data coordinating center using SAS statistical software version 9.2 (SAS Institute Inc, Cary, NC).

Hypotheses were tested by comparing the net effect at year 5 in each treatment group with the net effect in the control group. The net effect of training at year 5 was defined as mean improvement from baseline to year 5 in the intervention group minus the mean improvement from baseline to year 5 in the control group divided by the intrasubject SD of the Blom-transformed score. Similarly, the effect of each cognitive ability–specific booster training was defined as mean improvement from baseline to year 5 in the booster-trained group minus the mean improvement from baseline to year 5 in the nonbooster-trained group divided by the intrasubject SD of the score. Participants in the nonbooster group were those who received initial training but no booster training. Results are expressed as effect sizes (ie, difference in means divided by intrasubject SD) to allow direct comparison of different outcomes.

Power calculations were based on the assumptions of 6 Bonferroni-corrected 2-sided comparisons with an overall α error of .05 (.008 for each comparison), a correlation of 0.7 between baseline and follow-up (based on pilot data), and completion rates of 80% at 2 years and 65% at 5 years. Following the methods of Cohen,[41] the sample size of 2802 has 95% power to detect an effect size of 0.20. Based on the same assumptions, there is 90% power to detect booster training effects in the comparison between the subgroup receiving booster training in a training condition and the control group. In reporting statistically significant training effects, we used 99% confidence intervals (CIs; $P=.008$) to adjust for multiple comparisons.

RESULTS

Of 5000 individuals contacted for participation, 2832 persons were eligible, 905 (18.1%) were ineligible, and 1263 (25.3%) refused to participate (Figure 2). Compared with those who refused, those who participated were less likely to be women (76% vs 79%), were younger (mean age, 74 vs 75 years), more likely to be white (73% vs 60%), married (36% vs 27%), and better educated (mean of 13.5 vs 12.3 years). Their MMSE score was higher

Table 1. Baseline Characteristics

	No. (%) of Participants (N = 2802)*			
	Memory (n = 703)	Reasoning (n = 699)	Speed of Processing (n = 702)	Control (n = 698)
Age, mean (SD) [range], y	73.5 (6.0) [65-93]	73.5 (5.8) [65-91]	73.4 (5.8) [65-91]	74.1 (6.1) [65-94]
Female sex	537 (76.4)	537 (76.8)	538 (76.6)	514 (73.6)
Race				
White	524 (74.5)	504 (72.1)	523 (74.5)	503 (72.1)
Black	176 (25.0)	190 (27.2)	175 (24.9)	187 (26.8)
Other or unknown	3 (0.4)	5 (0.7)	4 (0.6)	8 (1.2)
Years of education, mean (SD) [range]	13.6 (2.7) [5-20]	13.5 (2.7) [4-20]	13.7 (2.7) [5-20]	13.4 (2.7) [6-20]
Married	257 (36.6)	249 (35.6)	242 (34.5)	259 (37.1)
Mini-Mental State Examination score, mean (SD) [range]	27.3 (2.1) [23-30]	27.3 (2.0) [23-30]	27.4 (2.0) [23-30]	27.3 (2.0) [23-30]
Short-Form 36 physical function score, mean (SD) [range]	69.1 (23.5) [5-100]	67.4 (24.1) [5-100]	69.7 (24.1) [0-100]	68.9 (24.6) [5-100]
Alcohol consumption†				
Nondrinker	298 (43)	302 (43)	295 (42)	350 (51)
Light drinker	341 (49)	347 (50)	362 (52)	313 (45)
Heavy drinker	60 (8)	46 (7)	42 (6)	30 (4)
Center for Epidemiologic Studies Depression Scale score, mean (SD) [range]	5.1 (5.3) [0-36]	5.5 (5.3) [0-36]	5.2 (5.0) [0-36]	5.1 (4.9) [0-36]
Disease history				
Hypertension	372 (53.1)	369 (53.2)	350 (50.1)	337 (48.8)
Diabetes	95 (13.5)	99 (14.2)	87 (12.4)	77 (11)
Transient ischemic attack or stroke	46 (6.6)	54 (7.8)	51 (7.3)	44 (6.3)
Ischemic heart disease	108 (15.5)	117 (17)	94 (13.5)	102 (14.7)
Congestive heart failure	30 (4.3)	44 (6.4)	27 (3.9)	37 (5.4)
High cholesterol	309 (44.6)	316 (46.4)	305 (44.3)	296 (43.1)
Myocardial infarction	79 (11.3)	78 (11.2)	76 (10.9)	76 (10.9)

*Unless otherwise indicated.
†Based on frequency of drinking alcohol and number of drinks on a typical day when drinking.

(mean 27.3 vs 26.8) and they were less likely to receive help with bathing (<1% needed help vs 2%). For both groups, 1% or fewer needed help with dressing and personal hygiene. Finally, those participating were less likely to have heart disease (11% vs 14%) and diabetes (13% vs 17%) but equally likely to have arthritis (57% vs 58%), stroke (0% in both groups), and cancer (6% in both groups).

Thirty individuals were randomized inappropriately in violation of the protocol and excluded from the analysis. Therefore, the analytic sample consists of 2802 randomized participants. Baseline characteristics for each of the 4 study groups appear in TABLE 1. Eighty-nine percent of participants completed treatment (>8/10 training sessions). Participants completing train-

Table 2. Effect of Training on Cognitive Outcomes From Baseline to Year 5

	Intervention Groups			
	Memory	Reasoning	Speed of Processing	Control Group
Memory (possible range: 0-132; n = 2790)				
Score at baseline, mean (SD)	81.0 (16.1)	80.7 (15.6)	80.9 (15.8)	79.4 (16.6)
Mean change from baseline to year 5	–1.0	–4.8	–5.3	–4.0
Effect size (99% CI)*	0.23 (0.11 to 0.35)	0.05 (–0.07 to 0.17)	0.05 (–0.07 to 0.17)	
Reasoning (possible range: 0-75; n = 2802)				
Score at baseline, mean (SD)	25.9 (12.2)	25.2 (12.0)	25.6 (11.7)	24.5 (12.0)
Mean change from baseline to year 5	4.3	8.1	4.2	5.2
Effect size (99% CI)*	–0.01 (–0.10 to 0.08)	0.26 (0.17 to 0.35)	0.02 (–0.06 to 0.11)	
Speed of processing (possible range: 0-1500; n = 2802)				
Score at baseline, mean (SD)	899.0 (272.5)	904.0 (264.5)	906.8 (260.6)	920.1 (267.3)
Mean change from baseline to year 5	79.1	119.6	241.8	–96.1
Effect size (99% CI)*	–0.01 (–0.15 to 0.13)	0.15 (0.01 to 0.29)	0.76 (0.62 to 0.90)	

Abbreviation: CI, confidence interval.
*Effect size defined as training improvement from baseline to year 5 minus control improvement from baseline to year 5 divided by the intrasubject SD of the Blom-transformed composite score. Positive effect sizes indicate improvement.

Table 3. Effect of Booster Training on Cognitive Outcomes From Baseline to Year 5*

	Intervention Groups		
	Memory	Reasoning	Speed of Processing
Memory (possible range: 0-132; n = 2790)			
Mean (SD) at baseline			
Booster	81.7 (15.7)	82.1 (15.2)	80.4 (16.3)
Nonbooster	80.2 (16.6)	79.1 (15.8)	81.5 (15.2)
Mean change from baseline to year 5			
Booster	–0.1	–5.0	–5.1
Nonbooster	–2.2	–5.1	–5.5
Effect size (99% CI)†	0.08 (–0.14 to 0.29)	0.14 (–0.07 to 0.36)	0.05 (–0.16 to 0.26)
Reasoning (possible range: 0-75; n = 2802)			
Mean (SD) at baseline			
Booster	25.8 (11.8)	25.6 (12.3)	25.4 (11.7)
Nonbooster	26.0 (12.6)	24.8 (11.8)	25.9 (11.8)
Mean change from baseline to year 5			
Booster	4.6	8.6	4.4
Nonbooster	3.9	7.3	3.8
Effect size (99% CI)†	0.09 (–0.06 to 0.24)	0.28 (0.12 to 0.43)	0.08 (–0.07 to 0.23)
Speed of processing (possible range: 0-1500; n = 2802)			
Mean (SD) at baseline			
Booster	900.7 (278.5)	895.2 (275.4)	904.5 (258.5)
Nonbooster	897.1 (266.1)	914.0 (251.8)	909.3 (263.1)
Mean change from baseline to year 5			
Booster	82.7	115.9	308.8
Nonbooster	74.7	121.9	161.4
Effect size (99% CI)†	0.01 (–0.23 to 0.25)	0.03 (–0.21 to 0.27)	0.85 (0.61 to 1.09)

Abbreviation: CI, confidence interval.
*Adjusted for baseline age and Mini-Mental State Examination score.
†Effect size defined as training improvement in the booster group minus improvement in the nonbooster group divided by intrasubject SD of the Blom-transformed composite score.

Table 4. Effect of Training on Functional Outcomes From Baseline to Year 5

	Intervention Groups (N = 2802)			
	Memory	Reasoning	Speed	Control Group
IADL difficulty (possible range: 0-38)				
Mean (SD) at baseline	1.3 (2.3)	1.5 (2.5)	1.5 (2.5)	1.3 (2.4)
Mean change from baseline to year 5	–0.7	–0.4	–0.3	–1.2
Effect size (99% CI)*	0.20 (–0.06 to 0.46)	0.29 (0.03 to 0.55)	0.26 (–0.002 to 0.51)	
Everyday problem solving (possible range: 0-56)				
Mean (SD) at baseline	36.5 (9.4)	36.4 (8.9)	36.4 (8.9)	35.6 (9.3)
Mean change from baseline to year 5	1.5	1.8	1.5	2.4
Effect size (99% CI)*	–0.15 (–0.28 to 0.02)	–0.08 (–0.21 to 0.05)	–0.05 (–0.18 to 0.07)	
Everyday speed of processing (possible range: –3 to 100)†				
Mean (SD) at baseline	4.1 (1.7)	4.1 (1.7)	4.0 (1.6)	4.2 (2.5)
Mean change from baseline to year 5	0.1	0.3	0.2	0.1
Effect size (99% CI)*	0.04 (–0.09 to 0.17)	0.09 (–0.04 to 0.22)	0.08 (–0.05 to 0.21)	

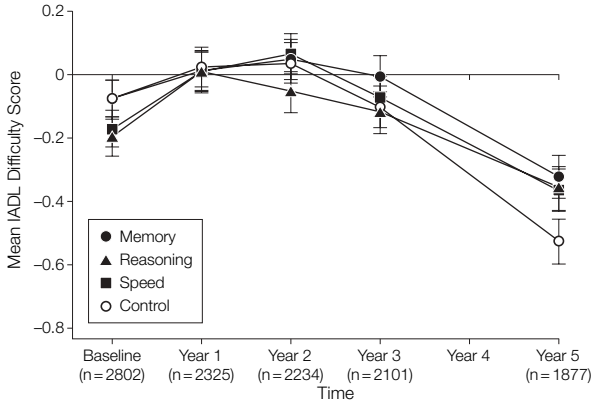
Abbreviations: CI, confidence interval; IADL, instrumental activities of daily living.
*Effect size defined as training improvement from baseline to year 5 minus control improvement from baseline to year 5 divided by intrasubject SD of the Blom-transformed composite score. Positive effect sizes indicate improvement.
†One component of this composite score is a standardized *z* score with a potential range of $-\infty$ to ∞.

ing were younger, had more education, and had higher baseline scores for the MMSE and cognitive function tests. Sixty-seven percent of the sample was retained 5 years after training despite the advanced age of the cohort. Selectivity of attrition was examined by multiple logistic regression modeling, considering sex, education, baseline age, MMSE score, and health status (number of health conditions; Short-Form 36) as well as intervention group and booster (vs nonbooster) status as predictors of retention at 5 years. Participants who were older, male, had less education and more health problems, and had lower cognitive function (indicated by lower baseline scores on the MMSE and the memory and reasoning tests) were less likely to be retained at 5 years. Importantly, there were no significant interactions between treatment group assignment and these covariates; that is, biases in retention are over the entire sample and not related to a particular treatment group, and therefore do not affect the between-group comparisons of intervention effects.

Training Effects on Cognitive Abilities

Each intervention produced immediate improvement in the cognitive ability trained[13] that was retained across 5 years (TABLE 2). Similarly, when controlling for baseline age and cognitive function, booster training for the reasoning and speed of processing groups produced significantly better performance (net of initial training effect) on their targeted cognitive outcomes[13] that remained significant at 5 years (TABLE 3).

Figure 3. Training Effects on Everyday Function by Self-reported Instrumental Activities of Daily Living (IADL) Difficulty Scores



The mean scores are Blom-transformed. Error bars indicate SE. The sample sizes for each time point represent the number of cases with complete data for the IADL difficulty score.

Training Effects on Daily Functioning

Self-Reported IADL Difficulty. At year 5, participants in all 3 intervention groups reported less difficulty compared with the control group in performing IADL (TABLE 4). However, this effect was significant only for the reasoning group, which compared with the control group had an effect size of 0.29 (99% CI, 0.03-0.55) for difficulty in performing IADL. Neither speed of processing training (effect size, 0.26; 99% CI, –0.002 to 0.51) nor memory training (effect size, 0.20; 99% CI, –0.06 to 0.46) had a significant effect on IADL. FIGURE 3 presents the standardized (Blom-transformed) mean IADL difficulty scores. Group mean IADL difficulty ratings improved through the first 2 years of the study (baseline through year 2). The decline in function for all groups is first evident between years 2 and 3. From years 3 to 5, the decline is

dramatically accelerated for the control group and to a lesser extent for the 3 treatment groups.

Performance-Based IADL Measures. Training had no general effect on the performance-based measures of everyday problem solving or everyday speed of processing (Table 4). However, after controlling for baseline age and cognitive function, the effect size for those participants in the speed of processing training group assigned to receive additional booster training was 0.30 (99% CI, 0.08-0.52) better for performance on everyday speed of processing compared with participants in this group not assigned to booster training (TABLE 5).

COMMENT

The ACTIVE study is the first large-scale, randomized trial to show that cognitive training improves cognitive function in well-functioning older adults and that this improvement lasts up to 5 years from the beginning of the intervention. In addition, this is the first trial to provide limited evidence that improvements in cognitive function can have a positive effect on daily function. Participants who received cognitive training reported less difficulty with IADLs 5 years after training compared with those in the control group. Participants in the 3 training groups reported an IADL decline of at least 0.20 SD less than the participants in the control group. The effect size reached statistical significance only for the reasoning training group but the effect sizes seen for memory and speed of processing training were similar to that for reasoning. We consider the relative comparability of the training effects across the 3 interventions to support the clinical meaningfulness of these results. Self-report of functioning repeatedly has been shown to predict loss of independence, increased use of health services, and mortality.[42] Participants in the intervention groups reported similarly lower declines in function compared with participants in the control group.

The finding of less decline in self-reported everyday function is conceptually complex. Training effects could reflect real benefits of intervention because each of the 3 trained cognitive abilities has been associated with everyday functioning.[22,43,44] It was not possible to blind participants to their treatment assignment (that is, participants knew whether they were receiving training). Thus, the effects of training on self-reported IADL function could also reflect personal beliefs and self-perception related to knowing whether one has received training. While self-report bias or overestimation of functional abilities has been reported in individuals with cognitive impairment,[45,46] it is unlikely in this study because ACTIVE participants were screened for dementia and showed improved cog-

Table 5. Effect of Booster Training on Functional Outcomes From Baseline to Year 5*

	Intervention Groups (N = 2802)		
	Memory	Reasoning	Speed of Processing
IADL difficulty (possible range: 0-38)			
Mean (SD) at baseline			
Booster	1.2 (2.1)	1.5 (2.7)	1.5 (2.4)
Nonbooster	1.5 (2.4)	1.5 (2.3)	1.5 (2.6)
Mean change from baseline to year 5			
Booster	–1.0	–0.2	–0.4
Nonbooster	–0.4	–0.6	–0.3
Effect size (99% CI)†	–0.09 (–0.49 to 0.31)	0.24 (–0.16 to 0.64)	–0.29 (–0.68 to 0.11)
Everyday problem solving (possible range: 0-56)			
Mean (SD) at baseline			
Booster	37.2 (9.1)	37.1 (8.9)	36.3 (8.9)
Nonbooster	35.8 (9.8)	35.6 (8.9)	36.4 (8.9)
Mean change from baseline to year 5			
Booster	1.4	1.5	1.4
Nonbooster	1.7	1.9	1.5
Effect size (99% CI)†	0.04 (–0.20 to 0.28)	0.22 (–0.02 to 0.46)	–0.02 (–0.25 to 0.21)
Everyday speed of processing (possible range: –3 to 100)‡			
Mean (SD) at baseline			
Booster	4.0 (1.6)	4.0 (1.6)	4.1 (1.8)
Nonbooster	4.1 (1.9)	4.1 (1.8)	4.0 (1.5)
Mean change from baseline to year 5			
Booster	0.2	0.3	0.3
Nonbooster	0	0.3	0.1
Effect size (99% CI)†	–0.008 (–0.23 to 0.22)	0.08 (–0.14 to 0.31)	0.30 (0.08 to 0.52)

Abbreviations: CI, confidence interval; IADL, instrumental activities of daily living.
*Adjusted for baseline age and Mini-Mental State Examination score.
†Effect size defined as training improvement in the booster group minus improvement in the nonbooster group divided by intrasubject SD of the Blom-transformed composite score.
‡One component of this composite score is a standardized *z* score with a potential range of $-\infty$ to ∞.

nitive function in their trained ability over the study period compared with the control group. These results suggest that for self-reported IADLs, a placebo control group that would facilitate blinding and additional analyses of the mechanisms of training-related improvement (eg, whether training-related improvements in self-efficacy mediated the self-rated functional improvements) will be important future directions for this kind of research.

There is growing consensus that assessment of daily function requires both self-report and performance-based measures.[47] The ACTIVE study is one of the few large-scale intervention studies to include both self-report and performance-based outcome measures of function to assess the breadth of intervention effects. Consistent with the study's conceptual model, we hypothesized that certain interventions would specifically affect 1 or more functional outcomes. This was observed for the performance-based functional measures. When controlling for baseline age and cognitive function, booster training for speed of processing showed a significant effect on the performance-based everyday speed of processing measure. This specific effect is consistent with prior research that indicated everyday speed of processing was more closely related to speed of processing[9,13] than to reasoning or memory. The fact that this effect occurred only in participants who received booster training, and not in those who received only initial training, may reflect a need for larger doses of training before effects can be observed in this more cognitively demanding outcome.

Across all outcomes, evidence for transfer of the effects of cognitive training to function was modest and was not observed until the 5-year follow-up. There are 2 possible explanations for these delayed outcomes. First, prior research has suggested a temporal lag between onset of cognitive decline and subsequent impact on daily function,[2-4] perhaps because of resulting difficulty in adapting to emerging physical limitations that affect tasks of daily living.[48,49] However, if cognitive ability is maintained or enhanced by training, then this could result in a gradual emergence of adaptive, compensatory strategies for dealing with physical limitations.[1] Second, delayed intervention effects on function may be attributable to the advantaged nature of the ACTIVE sample, and particularly the subset who received booster training. To select older adults most likely to benefit from cognitive training, persons with suspected cognitive and ADL decline were excluded from enrollment. This may have delayed the onset of functional disabilities in the control group until the 5-year follow-up. Only after the onset of decline in the control group could the positive training effects on function be observed in the intervention groups.

We are not aware of intervention trials with volunteer samples of older adults that include 5-year follow-up for direct comparison of retention rates. The 67% retention rate at 5 years is consistent with other longitudinal community-based studies resembling ACTIVE in terms of sample age and ethnicity and frequency and duration of study contact (eg, 70.6% in a 4-year study of blacks and whites in Chicago[50]; 61.6% in a 5-year study of blacks in Indianapolis[51]; and 59.6% in a 7-year study of Hispanics, whites, and blacks in New York City[52]). However, because these studies were not intervention trials, they did not have the same level of respondent burden as ACTIVE. Therefore, while the direct comparability of retention rates to other intervention trials cannot be made, the rates of these observational studies suggests that the retention rate in ACTIVE is quite acceptable given the burdensome nature of the study protocol.

In conclusion, declines in cognitive abilities have been shown to lead to increased risk of functional disabilities that are primary risk factors for loss of independence. The 5-year results of the ACTIVE study provide limited evidence that cognitive interventions can reduce age-related decline in self-reported IADLs that are the precursors of dependence in basic ADLs associated with increased use of hospital, outpatient, home health, and nursing home services,[53,54] and health care expenditures.[55] However, given the lag in the relationship between cognitive decline and functional deficits, the full extent of the interventional effects on daily function would take longer than 5 years to observe in a population that was highly functioning at enrollment. We consider these results promising and support future research to examine if these and other cognitive interventions can prevent or delay functional disability in an aging population.

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Statistical analysis: Marsiske, Morris, Stoddard, Wright.
Obtained funding: Willis, Tennstedt, Marsiske, Ball, Morris, Rebok, Unverzagt.
Administrative, technical, or material support: Willis, Marsiske, Ball, Elias, Koepke, Morris, Rebok, Unverzagt.
Study supervision: Willis, Tennstedt, Marsiske, Ball, Morris, Rebok, Unverzagt, Wright.
Financial Disclosures: Dr Ball owns stock in Visual Awareness Inc, which owns the patent for the Useful Field of View testing and training software. No other authors reported disclosures.
Funding/Support: ACTIVE is supported by grants from the National Institute on Aging and the National Institute of Nursing Research to Hebrew Senior Life (U01 NR04507), Indiana University School of Medicine (U01 NR04508), Johns Hopkins University (U01AG14260), New England Research Institutes (U01 AG14282), Pennsylvania State University (U01 AG14263), the University of Alabama at Birmingham (U01 AG14289), and the University of Florida (U01AG14276).
Role of the Sponsor: Representatives of the National Institute on Aging and the National Institute for Nursing Research were directly involved in the design of

the study, interpretation of the data, and preparation, review, and approval of the manuscript. These representatives also monitored the conduct of the study, collection, management, and analysis of the data.

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Acknowledgment: We thank Robin Barr, PhD, of the National Institute on Aging for his authorship of the request for applications and his continuing support and helpful comments throughout the conduct of the project. Dr Barr was not compensated for this assistance.

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