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RESEARCH ARTICLE

Vision and hearing difficulty and effects of cognitive training in older adults

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Abstract

BACKGROUND: Cognitive training is delivered visually and aurally. It is unknown whether self-reported sensory difficulty modifies the effects of cognitive training on cognition.

METHODS: Participants ($N = 2788$) in the Advanced Cognitive Training for Independent and Vital Elderly Study were randomized to training in memory, reasoning, speed of processing, or control. Differences in the 10-year effect of cognitive training on cognition by self-reported vision and hearing difficulty were assessed using linear mixed effect models.

RESULTS: Benefit (intervention vs. control) of reasoning training was smaller among participants with versus without vision difficulty (difficulty: –0.25, 95% confidence interval: [–0.88, 0.39], no difficulty: 0.58 [0.28, 0.89]). Benefit of memory training was greater for participants with versus without hearing difficulty (difficulty: 0.17 [–0.37, 0.72], no difficulty: –0.20 [–0.65, 0.24]).

DISCUSSION: Older adults with sensory loss have increased risk for cognitive decline; benefits of cognitive training may be greater for these individuals. Sensory loss should be considered in training design.

KEYWORDS
cognitive decline, cognitive training, hearing impairment, vision impairment

Highlights

- Memory training was more beneficial for participants with hearing loss.
- Participants with vision difficulties did not benefit as much from reasoning training.
- Low accessibility in design and learned compensation strategies may contribute.
- Consideration of sensory impairment in study design is needed.
- Inclusion of older adults with sensory impairment in cognitive training is needed.

1 | BACKGROUND

Cognitive training, a class of interventions that aims to improve cognitive function through engagement in cognitively challenging tasks, has shown to be an important component of multidomain interventions that have potential to reduce risk for dementia.[1–4] As the field of dementia prevention moves toward prioritizing implementation of effective interventions,[5] is it important to recognize how cognitive training may be more or less effective in certain populations. This understanding is beneficial for informing design and tailoring of interventions to effectively serve a diverse population of older adults.[6]

Differences in effectiveness of cognitive training by demographic and health characteristics have been investigated, particularly in the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) Study. The ACTIVE Study was a randomized controlled trial testing the effects of three cognitive training interventions (memory, reasoning, or speed-of-processing training [vs. no-contact control]) on cognitive and functional health.[7] The effect of memory training on memory performance over time was greater among participants with higher education and better self-rated health.[8] Higher baseline cognition was associated with larger effects of reasoning training.[9] The speed-of-processing training benefited older adults regardless of age, sex, education, and baseline cognitive and physical health status.[10] Additionally, greater adherence to training and participation in booster training were associated with larger effects of reasoning and speed-of-processing cognitive training, respectively.[11]

Older adults with vision and/or hearing loss are a subgroup for whom cognitive training interventions may be especially beneficial given the strong associations between vision and hearing loss and cognitive decline[12–20] and dementia.[21–26] Compared to older adults without sensory loss, people with vision loss have a 47% higher risk of dementia while people with hearing loss have nearly two times higher risk.[22,27] Both vision and hearing loss are prevalent in older adults. Approximately 9% of adults > 60 years[28] have vision loss; and two thirds of adults > 70 years have hearing loss.[29]

However, given the demands of cognitive training on visual and auditory processing, cognitive training may be less effective in older adults with vision and/or hearing loss if interventions were not specifically designed for people with low vision and to maximize hearing accessibility. One study, to our knowledge, has examined differential efficacy of cognitive training by sensory loss status. In a randomized controlled trial of speed-of-processing cognitive training, improved performance was seen on the Useful Field of View (UFOV) test in participants assigned to the intervention, with and without vision loss. However, speed-of-processing training was less beneficial for participants with self-reported eye diseases (e.g., cataracts, glaucoma, macular degeneration, diabetic retinopathy, optic neuritis, and retinopathy).[30] No studies, to our knowledge, have examined vision loss as a modifier of the effect of cognitive training in other cognitive domains. Hearing loss as a modifier of the effect of cognitive training has also yet to be examined.

Given the high prevalence of vision and hearing loss in older adults and the strong associations with cognitive decline and dementia, older adults with sensory loss are an important subgroup to study in the context of interventions to delay cognitive decline and reduce dementia risk. Therefore, in a post hoc, exploratory, subgroup analysis of the ACTIVE Study, this study investigates differences in the effect of the ACTIVE cognitive training on 5- and 10-year cognitive change by self-reported baseline vision difficulty and hearing loss.

RESEARCH IN CONTEXT

1. **Systematic review**: The authors reviewed the peer-reviewed literature (e.g., PubMed) on cognitive training and differences in the effect of cognitive training by participant characteristics. Prior studies have assessed effect modification by demographic and health characteristics (e.g., age, sex, education, health status) but no studies have investigated effect modification by hearing or vision status.
2. **Interpretation**: Participants with vision difficulties did not benefit as much from reasoning training, likely because training required more visually complex exercises (e.g., deciphering patterns across similar symbols). Memory training was more efficacious for participants *with* hearing loss, perhaps because training provided compensation strategies for overcoming cognitive load (increased effort for processing degraded auditory signals).
3. **Future directions**: Cognitive training interventions should consider sensory function in design and administration. Individuals with sensory loss have increased risk for cognitive decline and should not be excluded from cognitive training interventions as magnitude of benefit may be greater for these individuals.

2 | METHODS

2.1 | Trial design and participants

Data for this study come from the ACTIVE Study, the largest randomized cognitive training trial conducted to date. Details regarding the design of the ACTIVE Study are published elsewhere.[7] Briefly, in 1998, 2802 participants were randomized to one of three cognitive training intervention arms (memory, reasoning, or speed-of-processing training) or a no-contact control arm. Training occurred over ten, 60- to 90-minute, in-person, small-group sessions (3–5 participants per group). Training sessions were conducted over 6 weeks. A subset of participants who had completed the initial training (i.e., ≥8 sessions) received 4-session booster training 11 months and 35 months after initial training. Follow-up assessments occurred at 1, 2, 3, 5, and 10 years after initial training. Participants included in the ACTIVE Study were

≥ 65 years at baseline and were cognitively and functionally healthy. The analytic sample for this study includes all participants who have complete data on self-reported vision and hearing difficulties at baseline ($N = 2788$).

2.2 | Sensory loss and trial design

Sensory loss was included in design and implementation of the ACTIVE trial. Participants with vision loss (<20/50 visual acuity or self-reported extreme difficulty reading ordinary newspaper print), hearing loss (interviewer rated), or communicative difficulties that would prevent participation in cognitive training were excluded from participation in the trial. Additionally, for all training sessions, participants were asked to bring their sensory aids (e.g., glasses, hearing aids), if applicable, for use during the training. The study provided amplification devices if requested by the participant, but < 2% of participants requested to use one. Materials were printed in 14-point font, and participants were encouraged to sit near the front of the room if they had trouble seeing the materials presented or hearing the instructor.

2.3 | Cognitive training intervention

The memory training focused on using mnemonic strategies for improving memory in activities of daily living. The training emphasized using meaningfulness, organization, visualization, and association as strategies to aid in remembering lists (e.g., grocery lists), text-based information (e.g., medication information), and main ideas and details (e.g., in conversation). For example, in the "Memory Man" strategy, participants were taught to remember word lists by associating each item on the list with a location on the body (e.g., milk and shoulder) and then visualize the association (e.g., gallon of milk sitting on shoulder). Each strategy was introduced by a certified intervention trainer in a small-group setting (3–5 participants). Participants then practiced the strategies individually and as a group through lab-based practice exercises and through "real-life" exercises designed to mimic everyday situations.[7]

The reasoning training focused on problem-solving strategies. The training emphasized strategies to understand patterns and solve problems that follow a serial pattern or sequence (e.g., medication schedule). For example, the training used letter and number series to teach participants how to identify a pattern and apply the pattern to subsequent items in the sequence. Like the memory training, strategies were taught in a group setting and practiced individually and as a group. Participants practiced using lab-based exercises and through exercises related to everyday activities.[7]

The speed-of-processing training focused on visual search skills and ability to quickly focus on more than one task. The training was done via computer, and unlike the memory and reasoning training, the training was based on repeated drills and practice of speed-of-processing tasks. Participants engaged in tasks of increasing difficulty. At the lowest level, participants had to identify objects quickly flashed on the screen. Visual distractions flashed simultaneously with the primary stimulus in higher levels. At the most difficult level, simultaneous identification of an auditory sound was added to the task. Participants practiced these tasks individually.[7]

2.4 | Measures

2.4.1 | Cognitive training intervention

Each cognitive training intervention was modeled separately as a binary variable (i.e., memory intervention [1 = memory intervention, 0 = no-contact control], reasoning intervention [1 = reasoning intervention, 0 = no-contact control], speed-of-processing intervention [1 = speed-of-processing intervention, 0 = no-contact control]).

2.4.2 | Sensory loss

Self-reported near vision difficulty was measured by the question "How much difficulty do you have reading ordinary print in the newspaper with your glasses or contact lenses (if applicable)?" (no difficulty, a little or some difficulty). Self-reported hearing loss was measured by the question "Do you feel you have a hearing loss?" (yes/no). Distance visual acuity was measured using the GOOD-LITE LD-10 Chart in a GOOD-LITE Model 600A light box. Participants whose presenting distance visual acuity (with usual prescription lenses [if applicable]) measured worse than 20/40 were coded as having distance vision loss. Effect of visual acuity on cognitive training was assessed in a secondary analysis. A measure of audiometric hearing was not collected by the ACTIVE Study.

2.4.3 | Cognition

Cognitive ability in three domains (memory, reasoning, and speed of processing) was measured at baseline and at each follow-up visit (1, 2, 3, 5, and 10 years after baseline). Memory was measured by the Hopkins Verbal Learning Test—Revised, Rey Auditory Verbal Learning Test, and Rivermead Behavioral Memory Test (Paragraph Recall). Reasoning was measured by tests of Letter Series, Letter Sets, and Word Series. Speed of processing was measured by the UFOV test. Composite scores for each domain of cognition were created using the average of the standardized scores for each cognitive test of that domain.[7] Cognitive change over time was interpreted per one standard deviation change in cognitive performance.

2.4.4 | Covariates

Baseline demographics (age, sex, education), global cognition (Mini-Mental State Exam [MMSE]), and study design features (study site [University of Alabama, Birmingham; Indiana University School of

Medicine; Hebrew Rehabilitation Center for the Aged; Johns Hopkins University; Wayne State University; Pennsylvania State University], replicate [replicate 1—replicate 6]) were included as covariates based on methods published by Rebok et al.[11] A binary variable for participation in booster training was added as a covariate in sensitivity analysis.

2.5 | Statistical analysis

The distribution (frequency [proportion], mean [standard deviation]) of baseline participant characteristics was calculated by assigned intervention group. Linear mixed models with random intercepts and slopes (unstructured covariance structure) were used to assess change in performance on trained cognitive ability as a function of intervention group (dichotomous variable coded as 0 for control and 1 for intervention), time (categorical variable coded as 0 for baseline, 1 for 1-year follow-up, 2 for 2-year follow-up, 3 for 3-year follow-up, 5 for 5-year follow-up, and 10 for 10-year follow-up), reported sensory difficulty, and a three-way intervention x time x self-reported sensory difficulty interaction. Models were run separately for each type of cognitive training (memory, reasoning, and speed of processing) and for each self-reported sensory difficulty (dichotomous variable for self-reported near vision status [0 for no self-reported difficulty reading ordinary print in the newspaper and 1 for a little or some self-reported difficulty reading ordinary print in the newspaper] and self-reported hearing loss [0 for no self-reported hearing loss and 1 for self-reported hearing loss]). Within the category of self-reported sensory difficulty, estimates for the difference in per standard deviation change in trained cognitive ability from baseline between intervention and control groups were presented at the 5- and 10- year follow-up visits. Findings from the primary outcome paper report maintenance of training effect through the 10-year follow-up visit for reasoning and speed-of-processing training and through the 5-year follow-up visit for memory training.[11] P values for the intervention x time x self-reported sensory difficulty interaction were also reported. In secondary analyses, performance-tested distance vision as a modifier of cognitive training intervention effects was examined using the same methods as described for the primary analysis. In a sensitivity analysis, potential confounding by participation in booster training was assessed by the addition of a binary indicator for booster training participation to primary models. All analyses were considered exploratory.

3 | RESULTS

3.1 | Participant characteristics

At baseline, on average, participants (N = 2788) were 73.6 (standard deviation [SD]: 5.9) years and had 13.5 (SD: 2.7) years of education. Seventy-six percent of participants were female, 73% were White, and 26% were Black/African American. By self-reported sensory difficulty, 22% self-reported near vision difficulty and 43% self-reported hearing loss. Participants self-reported history of diabetes (13%), heart disease (11%), congestive heart failure (5%), hypertension (5%), and cancer (6%). Average score on the MMSE (range: 23–30) was 27.3 (SD: 2.0). There were no significant baseline differences in participants' characteristics between cognitive training intervention groups and the control group (Table 1). Adherence (completed at least 8 of 10 training sessions) was high for all interventions (memory training: 88%; reasoning training: 89%; speed-of-processing training: 90%). Intervention adherence was similar by self-reported hearing loss. Adherence to the reasoning training was lower among participants with self-reported near vision difficulty (84%) compared to participants without self-reported near vision difficulty (91%). Adherence to memory and speed-of-processing trainings was similar by self-reported near vision difficulty.

3.2 | Differences in the effect of ACTIVE cognitive training by self-reported sensory difficulty

Rebok et al. previously showed that, overall, the ACTIVE reasoning and speed-of-processing training had beneficial effects on maintenance of trained cognitive abilities over 10 years; beneficial effects of the memory training were maintained at 5 but not 10 years post-intervention.[11] Table 2 shows differences in the 5- and 10-year effects of memory, reasoning, and speed-of-processing training on trained cognitive abilities by self-reported vision and hearing difficulty.

Graphical presentation of predicted reasoning scores over time (Figure 1) shows participants who received reasoning training and did not self-report near vision difficulty performed consistently higher in reasoning ability than reasoning intervention participants with self-reported near vision difficulty and controls over follow-up. Reasoning ability among participants with self-reported near vision difficulty who received reasoning training was comparable to controls. The effect of reasoning training on reasoning ability significantly varied by self-reported near vision difficulty 5 years ($P = 0.03$) and 10 years ($P = 0.02$) post-intervention (Table 2). Estimates of 5- and 10-year differences in reasoning ability between intervention and control groups suggest greater benefit for participants who did not self-report near vision difficulty (5-year difference: 0.82; 95% confidence interval [CI]: 0.62, 1.03; 10-year difference: 0.58, 95% CI: 0.28, 0.89) compared to participants with self-reported near vision difficulty (5-year difference: 0.33; 95% CI: −0.07, 0.73; 10-year difference: −0.25, 95% CI: −0.88, 0.39). The effect of memory training and speed-of-processing training on trained cognitive ability was similar by self-reported near vision difficulty.

The benefits of memory training were greater in magnitude, although not statistically significantly different, at 5 years for those with self-reported hearing loss (difference: 0.69; 95% CI: 0.34, 1.05) compared to those without self-reported hearing loss (difference: 0.41; 95% CI: 0.11, 0.71; Table 2). Although the magnitude of the effect of memory training was greater for participants with (vs. without) self-reported hearing loss, graphical presentation of the data shows that participants with self-reported hearing loss who received mem-

TABLE 1 Participant characteristics by cognitive training intervention group ($N = 2788$), Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) Study, 1998–2008.

	Total $N = 2788$	Memory training $N = 698$	Reasoning training $N = 692$	Speed-of-processing training $N = 701$	Control $N = 697$
Age (years), mean (SD)	73.6 (5.9)	73.5 (6.0)	73.6 (5.8)	73.4 (5.8)	74.1 (6.0)
Sex, *N* (%)					
Male	670 (24.0)	164 (23.5)	160 (23.1)	163 (23.3)	183 (26.3)
Female	2118 (76.0)	534 (76.5)	532 (76.9)	538 (76.7)	514 (73.7)
Race/Ethnicity, *N* (%)					
White	2020 (72.5)	516 (73.9)	492 (71.1)	516 (73.6)	496 (71.2)
Black	722 (25.9)	175 (25.1)	186 (26.9)	175 (25.0)	186 (26.7)
Asian	7 (0.3)	1 (0.1)	2 (0.3)	2 (0.3)	2 (0.3)
Indian	4 (0.1)	0 (0.0)	2 (0.3)	0 (0.0)	2 (0.3)
Biracial	9 (0.3)	2 (0.3)	1 (0.1)	2 (0.3)	4 (0.6)
Other	26 (0.9)	4 (0.6)	9 (1.3)	6 (0.9)	7 (1.0)
Years of education, mean (SD)	13.5 (2.7)	13.6 (2.7)	13.5 (2.7)	13.6 (2.7)	13.4 (2.7)
Self-reported near vision difficulty, *N* (%)	603 (21.6)	137 (19.6)	162 (23.4)	146 (20.8)	158 (22.7)
Self-reported hearing loss, *N* (%)	1198 (43.0)	295 (42.3)	305 (44.1)	279 (39.8)	319 (45.8)
MMSE score (range 23–30), mean (SD)	27.3 (2.0)	27.3 (2.1)	27.3 (2.0)	27.4 (2.0)	27.3 (2.0)
Reported history of chronic conditions					
Diabetes, *N* (%)	358 (12.9)	95 (13.6)	99 (14.3)	87 (12.4)	77 (11.1)
Heart disease, *N* (%)	308 (11.1)	79 (11.4)	77 (11.2)	76 (10.9)	76 (10.9)
Congestive heart failure, *N* (%)	138 (5.0)	30 (4.3)	44 (6.4)	27 (3.9)	37 (5.4)
Hypertension, *N* (%)	1420 (51.3)	369 (53.1)	365 (53.1)	350 (50.1)	336 (48.7)
Cancer, *N* (%)	156 (5.6)	29 (4.2)	42 (6.1)	47 (6.7)	38 (5.5)

Abbreviations: MMSE, Mini-Mental State Examination; SD, standard deviation.

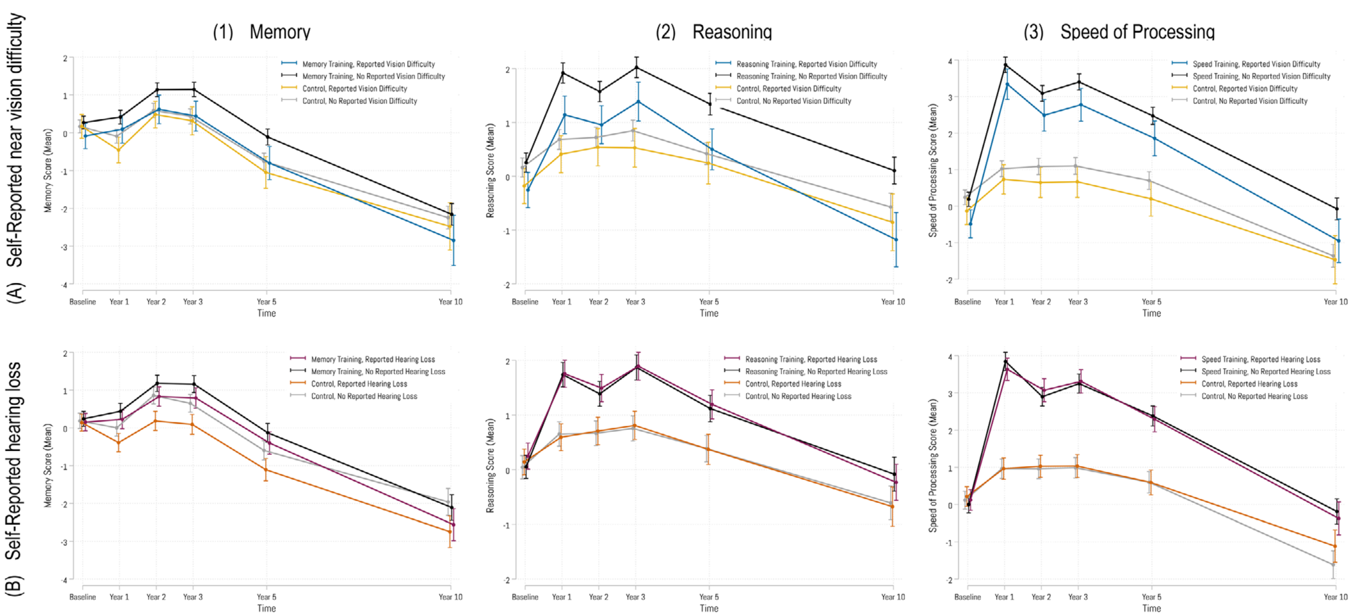

FIGURE 1 Multivariate linear mixed-effect models for adjusted[a] mean (1) memory, (2) reasoning, and (3) speed of processing scores over time by intervention group and (A) self-reported near vision difficulty and (B) self-reported hearing loss, Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) Study, 1998–2008. [a]All models adjusted for age, sex, education, global cognition (Mini-Mental State Exam), and study design features (study site [University of Alabama, Birmingham, Indiana University School of Medicine, Hebrew Rehabilitation Center for the Aged, Johns Hopkins University, Wayne State University, Pennsylvania State University], replicate [replicate 1–replicate 6]).

TABLE 2 Effect of self-reported near vision and hearing difficulty on 5- and 10-year cognitive training effects on trained cognitive ability ($N = 2788$), Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) Study, 1998–2008.

	Self-reported sensory difficulty (*N* intervention/ *N* control)	Estimate for 5-year difference in trained cognitive ability between intervention and control groups	95% CI	*P* value for interaction	Estimate for 10-year difference in trained cognitive ability between intervention and control groups	95% CI	*P* value for interaction
Self-reported near vision difficulty							
Memory training	No vision difficulty (561/539)	0.54	(0.28, 0.80)	0.89	−0.02	(−0.40, 0.36)	0.83
	Vision difficulty (137/158)	0.50	(−0.02, 1.02)		−0.12	(−0.97, 0.73)	
Reasoning training	No vision difficulty (530/539)	0.82	(0.62, 1.03)	0.03	0.58	(0.28, 0.89)	0.02
	Vision difficulty (162/158)	0.33	(−0.07, 0.73)		−0.25	(−0.88, 0.39)	
Speed-of-processing training	No vision difficulty (555/539)	1.82	(1.51, 2.13)	0.60	1.34	(0.94, 1.75)	0.32
	Vision difficulty (146/158)	2.01	(1.40, 2.62)		0.84	(0.03,1.72)	
Self-reported hearing loss							
Memory training	No hearing loss (403/378)	0.41	(0.11, 0.71)	0.24	−0.20	(−0.65,0.24)	0.29
	Hearing loss (295/319)	0.69	(0.34, 1.05)		0.17	(−0.37, 0.72)	
Reasoning training	No hearing loss (387/378)	0.73	(0.48, 0.97)	0.96	0.52	(0.15, 0.89)	0.52
	Hearing loss (305/319)	0.72	(0.44, 0.99)		0.34	(−0.07, 0.75)	
Speed-of-processing training	No hearing loss (422/378)	1.90	(1.55, 2.25)	0.70	1.54	(1.07, 2.01)	0.06
	Hearing loss (279/319)	1.79	(1.37, 2.22)		0.83	(0.25, 1.41)	

Notes: Linear mixed models with random intercepts and slopes were used to investigate whether baseline reported hearing and vision difficulties influenced cognitive training intervention effects on difference in trained cognitive ability from baseline to 5 and 10 years post-intervention. *P* value for interaction is the *P* value associated with the intervention × time × sensory difficulty interaction. Estimates interpreted per standard deviation change in cognitive ability. A positive value of the estimate for the difference between intervention and control groups indicates that the effect is in favor of the intervention group. All models adjusted for age, sex, education, global cognition (Mini-Mental State Examination), and study design features (study site [University of Alabama, Birmingham; Indiana University School of Medicine; Hebrew Rehabilitation Center for the Aged; Johns Hopkins University; Wayne State University; Pennsylvania State University], replicate [replicate 1–replicate 6]).
Abbreviation: CI, confidence interval.

ory training appeared to perform only as well as control participants without self-reported hearing loss (Figure 1). On average, the group that performed the best were participants without self-reported hearing loss who received the memory intervention. The effect of reasoning training and speed-of-processing training on trained cognitive ability was similar by self-reported hearing loss status; cognitive performance in each intervention group was nearly the same at all time points among participants with and without self-reported hearing loss (Figure 1).

In secondary analysis, differences in the effect of ACTIVE cognitive training by distance visual acuity were assessed (Table 3). As individuals with 20/50 vision or worse were excluded from the study, participants classified as having performance-tested distance vision difficulty in this analysis had visual acuity worse than 20/40. Due to low sample size in the performance-tested distance vision difficulty group (memory training: $n = 19$, reasoning training: $n = 19$, speed-of-processing training: $n = 20$, control: $n = 32$), estimates lack precision and should be interpreted with an abundance of caution. The effect of memory training on memory test performance was significantly greater for participants with (difference: 0.58; 95% CI: 0.34, 0.81) compared to without distance visual acuity impairment (difference: −0.77; 95% CI: −1.95, 0.41)

TABLE 3 Effect of performance-tested distance vision loss on 5- and 10-year cognitive training effects on trained cognitive ability ($N = 2788$), Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) Study, 1998–2008.

	Performance-tested distance vision loss (*N* intervention/ *N* control)	Estimate for 5-year difference in trained cognitive ability between intervention and control groups	95% CI	*P* value for interaction	Estimate for 10-year difference in trained cognitive ability between intervention and control groups	95% CI	*P* value for interaction
Memory training	No vision loss (562/549)	0.58	(0.34, 0.81)	0.03	0.01	(−0.35, 0.36)	0.49
	Vision loss (19/32)	−0.77	(−1.95, 0.41)		−0.78	(−2.94, 1.39)	
Reasoning training	No vision loss (539/549)	0.70	(0.51, 0.89)	0.40	0.44	(0.16, 0.72)	0.47
	Vision loss (19/32)	1.12	(0.17, 2.06)		-0.26	(−2.14, 1.62)	
Speed-of-processing training	No vision loss (575/549)	1.90	(1.62, 2.17)	0.06	1.24	(0.87, 1.61)	0.44
	Vision loss (20/32)	0.49	(−0.95, 1.94)		2.13	(−0.08, 4.34)	

Abbreviation: CI, confidence interval.

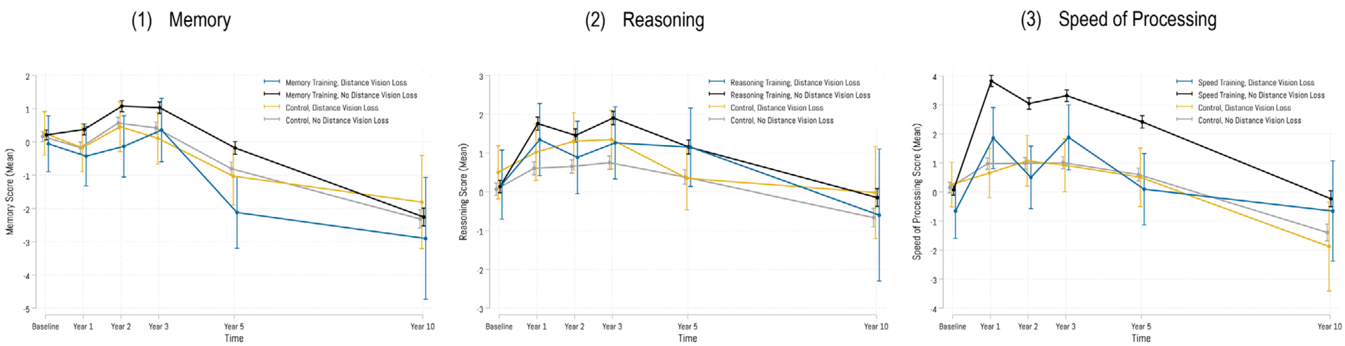

FIGURE 2 Multivariate linear mixed-effects models for adjusted[a] mean (1) memory, (2) reasoning, and (3) speed of processing scores over time by intervention group and performance-tested distance vision loss, Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) Study, 1998–2008.

5 years post-intervention. The effect of reasoning training on reasoning test performance did not significantly vary by distance visual acuity impairment status. For speed-of-processing training, graphical presentation of predicted speed of processing scores over time (Figure 2) shows participants who received speed-of-processing training and did not have distance visual acuity impairment performed consistently higher in tests of speed of processing than participants with distance visual acuity impairment who received speed-of-processing training and controls over 5 years. However, the magnitude of the effect of speed-of-processing training did not significantly vary by distance visual acuity impairment.

Finally, in sensitivity analyses, adjustment for participation in booster training did not alter primary findings (Table S1 in supporting information).

4 | DISCUSSION

The ACTIVE cognitive training trial had beneficial effects on trained cognitive abilities in participants both with and without sensory difficulty; however, magnitude of benefit differed by self-reported vision and hearing difficulty. Benefit of reasoning training was smaller among participants with vs. without vision difficulty while benefit of memory training was greater for participants with versus without hearing difficulty. The magnitude of benefit of the speed-of-processing training was similar by vision and hearing difficulty.

Few studies have assessed the impact of sensory loss on the effect of cognitive training. Many interventions, the ACTIVE study included, exclude participants with severe sensory loss given concerns about ability to participate in the intervention.[31] However, a limited number of studies have implemented cognitive training interventions specifically in populations with sensory loss.[30,32] Consistent with findings from the current study, speed-of-processing training was effective in improving cognitive performance (UFOV Test) in both participants with and without impaired near visual acuity or contrast sensitivity.[30] Similarly, Lawrence et al. reported pooled estimates from a meta-analysis of four cognitive training studies that included only older adults with hearing loss.[32] Cognitive training in older adults with hearing loss significantly improved overall cognition and working memory; but, certainty in the estimate was low due to small number of studies and variations in methodology and study design. No effect was seen for executive function, short-term memory, or attention/processing speed.[32]

Participants with self-reported near vision difficulty did not benefit from reasoning training as much as participants without self-reported near vision difficulty. One potential explanation is that those who self-reported near vision difficulty may not have been able to clearly see the reasoning training activities, which were mostly paper and pencil–based. Participants who self-reported near vision difficulty likely need reader glasses but do not have them. While training materials were printed in 14-point font, larger print may have been needed. The visual complexity of the practice problems (e.g., identification of patterns in sets of letters, numbers, and similar symbols) may have also contributed to difficulty learning and practicing strategies for participants with near vision difficulty. Additionally, as older adults with self-reported extreme difficulty reading ordinary newspaper print were excluded from the study, the difference in magnitude of benefit of reasoning training may be even greater for older adults with more severe vision loss.

Also, participants with near vision difficulties may require greater cognitive resources[33] to support visual processing, leaving fewer resources available for focusing on cognitive training. High cognitive load may have inhibited engagement and subsequent benefits of training in participants who self-reported near vision difficulty. Surprisingly, given the high demand on visual processing and visual search, no differences in the effect of speed-of-processing training were observed by self-reported vision difficulty in ACTIVE. It is possible that while vision difficulty as measured in the present study (self-reported difficulty reading newspaper print) does not contribute to differences in intervention effect, other types of unmeasured vision loss (e.g., visual field loss, macular degeneration) may, but were not tested in this study.

Lower training adherence (intervention dose) could also potentially explain reduced reasoning training benefits among participants who self-reported near vision difficulty.[11] Adherence to the reasoning training was slightly lower among participants with self-reported near vision difficulty (84% completed at least 8 of 10 training sessions) compared to participants without self-reported near vision difficulty (91%). Adherence to memory and speed-of-processing trainings was similar by self-reported near vision difficulty. Another consideration is bias in cognitive test performance due to sensory loss as performance relies on ability to see and hear to complete the tests. A recent study investigated whether neurocognitive test performance in older adults may be biased among those with sensory loss. Although there was some evidence of bias by vision loss for some tests that do not rely on vision and by hearing loss for some tests that do not rely on hearing, sensory loss may not impact performance if tests are performed in optimal conditions (e.g., quiet room, in person/face to face).[34] Further investigation of bias by hearing and vision loss in cognitive tests that rely primarily on hearing and vision impairment is needed.

Although estimates did not reach statistical significance, we found a suggestion that participants with (vs. without) self-reported hearing loss may be particularly responsive to memory training. Memory training may serve as a compensation mechanism to aid in preserving memory ability in the face of cognitive load due to hearing loss. Allocation of cognitive resources for processing a degraded auditory signal leaves fewer resources to maintain other cognitive functions. Working memory, in particular, has been shown to be impacted.[35] However, availability of and ability to activate compensation mechanisms can potentially buffer cognitive impairment associated with high cognitive load.[33,36] Potentially, by using mnemonic strategies taught in the ACTIVE memory training, participants with self-reported hearing loss may have been better able to compensate for memory deficits associated with cognitive load. Of note, with training, memory performance among participants with self-reported hearing loss was raised to the level of peers in the control group without self-reported hearing loss, suggesting that memory training may have important benefits for individuals with self-reported hearing loss, but that it is not able to compensate completely for the impact of hearing loss on cognition.

As the largest cognitive training trial to date, ACTIVE's large sample size allows for the investigation of subgroup differences in intervention effect. However, we were limited, as in any secondary analysis, by the measures collected. The vision difficulty measure allowed us to assess self-reported near vision, but we were unable to assess other measures of visual function (e.g., performance-tested near vision, contrast sensitivity) or the extent to which vision impairment impacts functional ability. We assessed distance visual acuity in secondary analysis, but estimates lacked precision due to low numbers. Additionally, with a binary measure of self-reported hearing loss, we cannot assess audiometric hearing loss, severity of self-reported hearing loss, or the extent to which hearing loss impacts functional ability. Observed differences in intervention effect can only be interpreted in reference to the types of vision and hearing loss measured. Unmeasured components of sensory loss may affect efficacy of certain types of cognitive training based on intervention design (e.g., visual field loss impact on the effect of speed-of-processing training), but these differences were unable to be captured in the present study.

Second, as with any longitudinal study, the ACTIVE study experienced attrition (67% of the baseline sample was retained 5 years post-intervention; 44% was retained 10 years post-intervention) over study follow-up.[11] Participants lost to follow-up were more likely to be older, male, and have worse physical and cognitive function. Minimal differences in attrition were observed by self-reported hearing loss and intervention group (Table S2 in supporting information), suggesting that, while findings may underestimate training effects due to attrition, observed differences in training effects are likely not attributable to differential attrition by self-reported hearing loss. Attrition was slightly higher among participants with self-reported near vision difficulty; findings may underestimate differences in training effect, particularly memory training, by self-reported near vision difficulty. Moreover, the impact of missing data in ACTIVE has also been previously addressed; Rebok et al. found that primary intervention findings were robust to extensive sensitivity analysis using multiple imputation for missing data.[11] Also, individuals with severe vision or hearing loss that would prevent participation in the intervention were excluded. Thus, findings from this study only reflect individuals with better than 20/40 vision, no difficulty or only a little or some difficulty reading newspaper print, and individuals without severe hearing loss (interviewer rated). The effect of ACTIVE cognitive training in older adults with severe sensory loss is unknown and future research is needed. Finally, given that analyses were exploratory, we focus on the patterns of effect and did not adjust for multiple comparisons.

Individuals with sensory loss may benefit the most from interventions designed to improve cognitive health as risk for cognitive decline and dementia is high among older adults with hearing and vision loss. Purposive design of interventions accessible for participants with sensory loss may increase intervention efficacy in this subgroup. Accessibility integrated into intervention design and applied to all participants is best for reducing stigma associated with certain accommodations. Further, as many interventions include virtual or digital components, thoughtful incorporation of accessible technology into design (e.g., multi-modal presentation of content, sound amplification options, subtitles, magnification, color contrast) is critical. Additionally, individuals with sensory loss are generally excluded from interventions to reduce dementia risk out of concern for ability to participate in the intervention.[2,7] Increased accessibility allows interventions to expand inclusion criteria to include individuals with more severe sensory losses. Individuals may feel more comfortable participating as well if interventions were designed to be accessible and/or accommodations and assistive technologies, particularly technologies designed to reduce stigma, were made available. Continued investigation of the effects of cognitive training intervention in samples in which all levels of sensory loss severity (no sensory loss to severe sensory loss) are represented is needed. Furthermore, sensory aids, such as corrective lenses, hearing aids, and amplification devices are effective in improving vision and hearing as well as potentially slowing cognitive decline[37]; cognitive training may serve as an additional tool to further benefit cognition in combination with sensory aids and therapeutic techniques.

Cognitive training in the ACTIVE study benefited participants both with and without self-reported sensory difficulty, but differences in magnitude of benefit were observed by hearing and vision difficulty. Design of more accessible interventions may improve intervention efficacy among participants with sensory loss.

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CONFLICT OF INTEREST STATEMENT

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CONSENT STATEMENT

Study procedures were approved by institutional review boards at participating institutions, and all participants provided written informed consent.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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