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A cognitive training intervention improves modality-specific attention in a randomized controlled trial of healthy older adults

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Abstract

Age-related deficits in cognitive and sensory function can result in increased distraction from background sensory stimuli. This randomized controlled trial investigated the effects of a cognitive training intervention aimed at helping healthy older adults suppress irrelevant auditory and visual stimuli. Sixty-six participants received 8 weeks of either the modality-specific attention training program or an educational lecture control program. Participants who completed the intervention program had larger improvements in modality-specific selective attention following training than controls. These improvements also correlated with reductions in bimodal integration during selective attention. Further, the intervention group showed larger improvements than the control group in non-trained domains such as processing speed and dual-task completion, demonstrating the utility of modality-specific attention training for improving cognitive function in healthy older adults.

Keywords: Attention; Distraction; Cognitive aging; Auditory; Visual; Training

1. Introduction

Normal aging is accompanied by changes in many sensory and cognitive domains, causing impairments in memory, communication, balance, and mobility that can lead to difficulty performing basic activities of daily living (Cahn-Weiner et al., 2000; Hedden and Gabrieli, 2004; Owsley and McGwin, 2004; Wood et al., 2005; Murphy et al., 2006; Inzitari et al., 2007; Maki et al., 2008). Thus, a major goal of aging research is to develop methods for maintaining independence and quality of life for older adults. Because the brain retains some plasticity with age, interventions aimed at training cognitive abilities may provide a means for maintaining or strengthening cognitive skills in healthy older adults (Kempermann et al., 2002; Jones et al., 2006; Acevedo and Loewenstein, 2007). In fact, several cognitive training programs have been shown to be effective at improving healthy older adults' memory, reasoning, speed of processing, and dual-task performance (Ball et al., 2002; Edwards et al., 2005; Bherer et al., 2006; Mahncke et al., 2006; Willis et al., 2006; Erickson et al., 2007).

Although the neural mechanisms that underlie age-related cognitive decline remain equivocal, age-related reductions in brain volume (Raz et al., 2004) and cortical thickness (Salat et al., 2004) are most pronounced in the prefrontal cortex, and executive processes supported by the prefrontal cortex, including attention, inhibition, and working memory, are highly susceptible to age-related declines (West, 1999; Grady and Craik, 2000; Andres et al., 2008). Deficits in these executive functions can impair older adults' performance on a broad range of cognitive tasks, as age-related increases in distraction from task-irrelevant visual stimuli, sounds, and speech can interfere with processing information that is relevant to the task (Alain and Woods, 1999; Tun et al., 2002; McPhee et al., 2004; Andres et al., 2006; Healey et al., 2008). For example, older adults' responses to visual stimuli are slowed more than younger adults' when the visual stimulus is preceded by a novel sound (Andres et al., 2006).

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In addition to the cognitive factors that influence older adults' task performance, age-related declines in sensory acuity and alterations in how stimuli from different sensory modalities are integrated together can also play a role in functional abilities (Wood et al., 2005; Murphy et al., 2006). Murphy et al. (2006) demonstrated that the comprehension and memory deficits that older adults experience when processing two-person conversations can be eliminated by compensating for older adults hearing difficulties. However, older adults still performed worse than younger adults when the two talkers were spatially separated (Murphy et al., 2006). These results indicate that although ameliorating basic sensory impairments can improve older adults' ability to process sensory information, additional means may be required to minimize age-related deficits.

Enhancing the sensory signals that older adults receive from the environment is one method for recovering function; another technique is to reduce the amount of background noise being processed along with the relevant sensory information. Older adults exhibit enhanced integration of information from multiple sensory modalities compared to younger adults (Laurienti et al., 2006; Peiffer et al., 2007; Diederich et al., 2008). The inappropriate integration of irrelevant or non-matching sensory stimuli can serve to increase noise and interfere with processing of relevant information (Alain and Woods, 1999; Strupp et al., 1999; Andres et al., 2006). One cognitive mechanism for reducing such cross-modal noise is modality-specific selective attention, which allows us to focus on information in one modality by suppressing the processing of stimuli in the ignored modality (Spence and Driver, 1997; Spence et al., 2001). Selective attention to either the auditory or visual modality has been demonstrated to eliminate the integration of congruent audiovisual stimuli in younger adults (Talsma et al., 2007; Mozolic et al., 2008); however, older adults still demonstrate increased multisensory integration during selective attention (Hugenschmidt et al., 2009), and it is unknown whether improving selective attention in older adults could reduce susceptibility to distraction from irrelevant sensory stimuli.

Our goal for this study was to investigate the effects of selective attention training in healthy older adults. The training program was designed to improve participants' ability to suppress background auditory and visual stimuli in an effort to decrease the amount of distraction experienced by older adults, and consequently improve their ability to process relevant information. Our hypothesis was that successful completion of the training program would reduce the influence of an ignored sensory modality on tasks that require modality-specific selective attention. Additionally, we investigated whether improvements would generalize to a wide variety of cognitive tasks, with the idea that improved sensory processing could have a positive effect on a broad range of cognitive functions that rely on the suppression of cross-modal noise.

2. Methods

2.1. Participants

Participants were recruited from the community for this randomized, controlled, single-blind study. All study procedures were approved by and conducted in accordance with the Wake Forest University School of Medicine Institutional Review Board. All participants signed an informed consent and were compensated approximately US$ 20 per hour for their participation in the study. Seventy-five adults between the age of 65 and 75 were screened for eligibility. Sixty-six of these participants (mean age = 69.4, 35 women) were determined to be eligible for the study and were subsequently randomized to either the treatment or the control group. Randomization was completed in blocks of 8–10 subjects and stratified based on gender. Exclusion criteria included any of the following: visual acuity less than 20/40 with corrective lenses; colorblindness; hearing loss greater than 50 dB at 1000 or 2000 Hz; dementia or mild cognitive impairment indicated by a score on the Mini-Mental Status Exam that was below the 5th percentile for participant age and education level (Bravo and Hebert, 1997); current substance abuse indicated by a score greater than 10 on the Alcohol Use Disorders Identification Test or an evaluation of participant medical history; untreated depression, evaluated using the Medical Care Corporation survey (www.mccare.com); previous brain surgery or CNS trauma, neurological disorder, or use of antipsychotic and/or antiepileptic drugs, as determined by an evaluation of participant medical history. Demographic data for participants are summarized in Table 1.

2.2. Design

Following eligibility screening and randomization, all participants completed a battery of behavioral tests to evaluate baseline functioning in several cognitive domains. Within 1 week of this behavioral testing session, all participants began 8 weeks of training. For both the treatment and control training programs, participants came to the laboratory for 1 h each week (total training time = 8 h). Within 1 week of completing their respective training programs, all participants were again administered the same battery of behavioral tests that they had completed prior to training. Participants also completed subsequent follow-up exams out to one month post-training, and

Table 1
Demographic data for participants in the treatment and control groups.

	Treatment	Control	*p*-Value
Age (years)	69.4 (3.2)	69.4 (2.5)	1.00
Sex (# females)	17	18	
Education (years)	15.6 (2.2)	16 (3.4)	0.18
MMSE (score)	28.3 (1.5)	28.5 (1.9)	0.66

Demographic data did not differ for participants randomized to the treatment and control groups on a 2-tailed *t*-test. Mean values are presented with standard deviations in parentheses.

a subset of these participants underwent MRI scans; these additional data will be considered in subsequent reports.

2.3. Interventions

Participants were randomized to receive either the attention training program or the control educational lecture program. Participants were blind to the treatment and control designations of these two groups, and were informed only that the study was designed to investigate the effects of two different training programs.

2.3.1. Treatment group

The treatment program was an individual training program focused on visual and auditory selective attention. The goal of this program was to provide participants with repeated practice at actively suppressing distracting background noise during task performance. Training difficulty increased adaptively, so that each participant's progress through the training was based on his or her performance on previous tasks. With this training design, all participants were able to progressively improve performance at their own pace. In this way, participants were continually challenged to ignore very salient visual and auditory distractors in order to complete demanding cognitive tasks.

The program paired visual and auditory tasks with cross- and within-modality distractors, creating four different task categories: (A) visual tasks with visual distractors, (B) visual tasks with auditory distractors, (C) auditory tasks with auditory distractors, and (D) auditory tasks with visual distractors. Tasks from each of these categories were presented with equal frequency, in the following order: C, D, B, A, repeat. In each category, tasks included detecting, identifying, classifying, and/or sequencing visual or auditory presentations of letters, words, and numbers. Other tasks also included simple mathematical operations (addition or subtraction). Several task components were adapted from the APT-II (Lash & Associates Publishing/Training, Inc., Wake Forest, NC), a commercially available program that has been used to rehabilitate attentional processes in patients with brain injury (Sohlberg and Mateer, 1987; Sohlberg et al., 2000) and schizophrenia (Lopez-Luengo and Vazquez, 2003).

In order to ensure that any training effects were not due to practice with keyboards and computers, participants in the treatment group did not use a computer at any time in the training program. All visual tasks and distractors were projected onto a 4 ft × 5 ft movie screen by an overhead LCD projector. Participants were seated approximately 60 in. from the projection screen and viewed all visual stimuli on this movie screen, not on a computer monitor. All auditory tasks and distractors were presented through the speakers of the overhead LCD projector at a loud but comfortable level (70–80 dB). Stimuli and distractors were transmitted to the projector and overhead speakers from a laptop computer running Presentation software (www.neurobs.com). Participants gave responses for each task with verbal or written answers or by pressing a handheld buzzer for detection tasks. At no time did they make responses using a computer or keyboard. An experimenter positioned behind the participant gave all task instructions, controlled stimulus presentation, monitored performance and compliance, and provided feedback to the participant.

During each visual task with visual distractors, visual stimuli were presented in the center of the screen in white font. Each number or letter subtended ∼1.4° of visual angle. The number, letter, or word stimuli were presented within a black box that subtended ∼19° of visual angle. Aside from this black box positioned in the center of the screen, the entire projection screen contained the visual distractors (∼53° of visual angle). Thus the visual stimuli appeared to be overlaid in front of the ongoing visual distraction. Visual distractors were series of short (5–15 s) stock footage video clips of people, places, and events (Time Image Digital Film Library, www.timeimage.com). Several unique video clips spliced together provided distraction for the duration of each task (2–5 min). On visual tasks with auditory distractors, the visual stimuli appeared in the center of a black screen and sounds were presented via the overhead speakers. On auditory tasks with visual distractors, the entire screen contained the distraction display, except for a small black box containing a white fixation cross (∼3° of visual angle). During auditory tasks with auditory distractors, both the task and distractor stimuli were presented through overhead speakers. Task stimuli were mixed with the distractor tracks using Goldwave audio editing software (www.goldwave.com). Thus, participants heard the task stimuli embedded within the ongoing distractor noise. Auditory distractors were series of short stock audio tracks of weather, animal, instrument, machine, and crowd noises (www.soundfx.com). Several unique audio tracks edited together provided distraction for the duration of each task. One example task (category B, difficulty level 3) required participants to complete patterns of visually presented numbers and letters (e.g. *Z*, *Y*, *X*, *W*; or 2, 3, 5, 8), while ignoring continuous auditory noise (thunderstorms, playground noise, barking dogs, city traffic, etc.).

To establish task difficulty levels, training tasks were piloted on one old (age 76) and five young (mean age = 29) subjects. Four to five tasks from each category (A–D) were grouped together in five difficulty levels, yielding a total of 88 potential tasks available for completion during the training program. Training for all participants began with easy tasks in each category, and task difficulty increased as training progressed. In order to advance to each subsequent task, participants were required to complete the current task with 80% accuracy. If a participant did not achieve 80% accuracy, the task was repeated until 80% accuracy was reached. If this accuracy level could not be reached in 6 attempts, the task was replaced by an alternate one of similar difficulty. Verbal feedback was provided to participants after completion of each task, informing them of their accuracy rate on the task and whether they would be repeating the task or beginning a new one. Additionally, participants were kept appraised of the current difficulty level and were alerted when the task difficulty would be increased. This procedure provided an adaptive training experience for each participant, as those with highly accurate performance on the tasks quickly progressed on to more difficult tasks, and those with lower accuracy rates received additional practice on each task until performance criteria was reached and the level of task difficulty could be increased. Progression through training therefore required improvements in performance, because all participants were able to advance to appropriate difficulty levels where multiple attempts were required to reach 80% accuracy. There were no cases where a participant was not able to improve with repetition and progress from easy to harder tasks over the course of training.

2.3.2. *Control group*

The control program was a small-group educational lecture series focused on topics in healthy aging. Because this program was designed to control for the time commitment and interactive nature of the treatment program, control participants visited the lab for the same duration and number of sessions. Additionally, by conducting control lecture sessions in small groups with approximately four study participants and three study staff members, participants in the treatment and the control groups had similar interactions with study staff. Each session began with pre-test questions, followed by a 30-min lecture by a topical expert. Subjects then participated in an interactive component where they were encouraged to apply information from the lecture. Each participant was also required to complete a post-test covering the same questions administered before the lecture. The interaction with topical experts, including doctors, nurses, and therapists, as well as the administration of pre- and post-tests served to maintain the single-blind design of the study. That is, participants in the control group did not know that they were part of the control program; they were under the impression that they were just completing a different training regimen than the treatment group.

2.4. *Evaluations*

To evaluate the effects of the attention training program, we administered tests of modality-specific selective attention. Additionally, to determine if the intervention generalized to other domains, we administered several assessments of cognitive performance and subjective feelings of well-being. As the attention training program utilized a hierarchical progression requiring mastery (80% accuracy) at low levels in order to move to more difficult levels, none of the training tasks were administered during evaluation.

2.4.1. *Primary outcomes*

Our primary outcome measures in this study were accuracy and response time (RT) on two tasks of modality-specific selective attention. These response competition paradigms required participants to make a speeded choice response to a relevant visual target (the letters *X* and *N*) while ignoring irrelevant distractors. The first task, adapted from Tellinghuisen and Nowak (2003), required subjects to ignore auditory (*cross-modal*) distractors (Tellinghuisen and Nowak, 2003) and the second task, adapted from Maylor and Lavie (1998), required subjects to ignore visual (*within-modality*) distractors positioned to the left or right of the target (Maylor and Lavie, 1998). These tasks were chosen as direct measures of the effectiveness of attention training using cross- and within-modality distractors, respectively.

For the cross-modal distractor task, the target letter *X* or *N* was positioned within a circular array that could contain 1 or 7 additional letters (Fig. 1A). Increasing the number of letters in the array allowed us to investigate task performance at varying perceptual loads. The auditory distractors were the letters *X*, *N*, *T*, and *L*. These auditory distractors were paired with the visual targets to produce *congruent trials* (auditory letter matched the target visual letter, e.g., hear *N*, see *N*), *incongruent trials* (auditory letter was the opposite response choice, e.g., hear *X*, see *N*), and *neutral trials* (auditory letter was not a response choice, e.g., hear *T*, see *N*). All letters were presented in light gray font on black background, and subjects were instructed to maintain fixation on a cross in the center of the screen for the duration of the session. Auditory letters were presented through speakers located on either side of the monitor.

Participants completed a total of 144 trials, and equal numbers of congruent, incongruent, and neutral trial types were presented randomly within the session. The total number of letters in the array (set size = 2 or 8) and the target position within the array on each trial was also randomly ordered and counterbalanced across trial types. Participants responded by button press with the left and right index finger, and the left/right response mapping was counterbalanced across participants. Stimulus presentation and response collection were conducted using E-Prime software (www.pstnet.com). Each trial began with a fixation period of 850–1150 ms (mean = 1000 ms). The target display and auditory distractor were then presented for 300 ms, followed by a reply-terminated response interval of up to 3000 ms.

For both accuracy and RT, we computed a measure of *total interference* for each participant, which was the difference between performance on congruent trials and performance on incongruent trials. We performed analyses of variance on the group means for accuracy and RT total interference using set size and test session as the repeated measures, and training group as the between group factor. This yielded a $2_{\text{set size}} \times 2_{\text{session}} \times 2_{\text{group}}$ mixed model ANOVA for accuracy data, and a similar ANOVA for RT data. Our hypothesis was that this analysis would yield a significant session × group interaction, indicating that the treatment group showed larger reductions in interference than the controls. Post hoc *t*-tests were used to further explore significant interaction terms.

The within-modality distractor task (Fig. 1B) was very similar to the cross-modal task, with the following differences: (1) the visual distractor was a letter presented to the

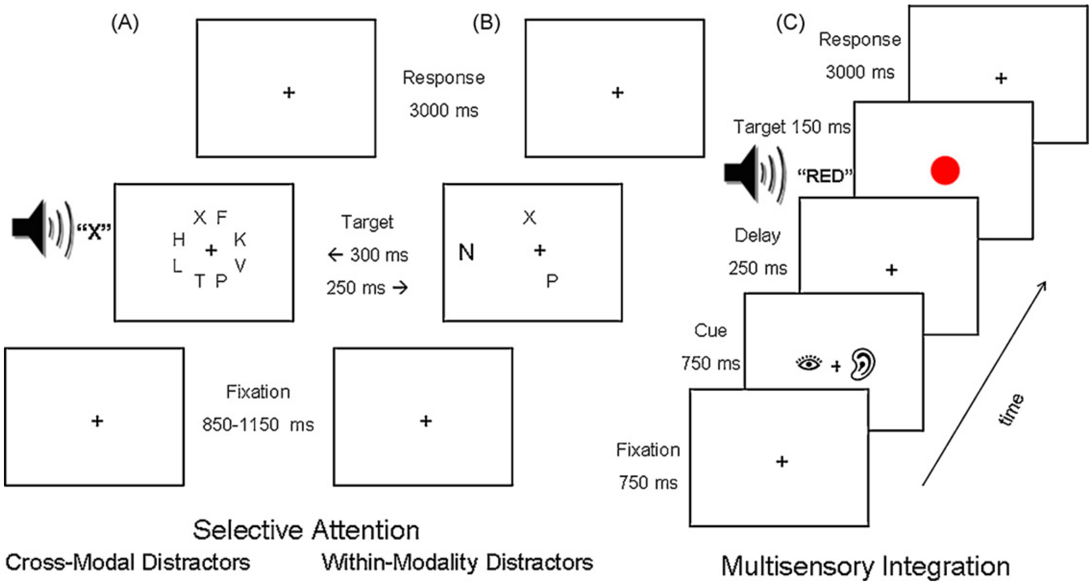

Fig. 1. Sequence of trial events for primary and secondary outcome measures. In this trial depicted for the selective attention task with cross-modal distractors, participants were required to determine whether there was an X or an N presented in the visual array (set size = 8), while ignoring the auditory presentation of a letter (congruent trial; A). In the trial depicted for the selective attention task with within-modality distractors, participants were again required to determine whether there was an X or an N presented in the visual array (set size = 2); however in this paradigm they must ignore a distracting letter presented to the left or right of the central array (incongruent trial; B). For this example trial of the multisensory integration task, participants were cued to divide attention between the auditory and visual modalities, and then determine whether the target was the color red or blue (multisensory target; C).

left or right of the central target array; (2) only neutral and incongruent trials types were presented, thus a measure of *distractor cost* was computed as the difference between performance on neutral trials and performance on incongruent trials; (3) the target and distractor were presented for 250 ms rather than 300 ms; (4) set sizes of 2 and 6 letters, rather than 2 and 8, were presented and analyzed in the $2 \times 2 \times 2$ mixed model ANOVAs for accuracy and RT. Our hypothesis for this task was based on the work of Maylor and Lavie (1998), who demonstrated a larger distractor cost for older adults than younger adults at low perceptual loads (small set sizes), but not at higher levels of perceptual load because older adults' reduced attentional capacity prevents processing of the distractor. We predicted that if training improved within-modality selective attention, the treatment group would have reduced distractor costs at set size 2, and stable or increased distractor costs at set size 6, relative to the control group. This pattern of results in older adults after training would be more consistent with the performance of young adults on this task, who show little distraction at low perceptual loads, and more distraction at higher perceptual loads due to their capacity to process the distractor.

2.4.2. Secondary outcomes

We hypothesized that improved modality-specific attention capabilities following attention training would be demonstrated not only on direct tests of selective attention, but that improved suppression of background sensory noise would also be reflected in reduced integration of ignored sensory stimuli on a test of multisensory integration. Therefore, our second main outcome measure was performance on an audiovisual multisensory integration task that allowed us to evaluate the influence of stimuli in the ignored sensory modality (Laurienti et al., 2006; Mozolic et al., 2008).

This cued discrimination paradigm required participants to choose between the colors red and blue during different attention conditions (Fig. 1C). During each trial, stimuli were presented in either the auditory modality, the visual modality, or simultaneously in both the auditory and visual modalities. Auditory stimuli were the words *red* and *blue*, visual stimuli were red and blue color-filled circles presented on a black background, and multisensory stimuli were simultaneous presentations of matching auditory and visual stimuli. Forty-eight auditory, 48 visual, and 72 multisensory trials were presented in random order. Participants responded by button press with the left and right index finger, and the red/blue response mapping was counterbalanced across participants.

Each trial began with participants fixating on a gray cross on a black background for 750 ms. Following fixation, a 750 ms visual cue was presented to alert participants to direct their attention to the auditory modality or the visual modality, or to divide their attention across both the auditory and the visual modalities in preparation for the target. After a 250 ms delay, the target was presented for 150 ms, followed by a response interval that terminated when a response was made, or after 3000 ms if no response was made. Participants were instructed that an auditory attention cue could be followed by a unisensory auditory target or a multisensory target, but they were to pay attention to the auditory modality. Similarly, the visual attention cue could be followed by a unisensory visual target or a multisensory target, but attention was to be focused on the visual modality. The divided attention cue could be followed by an auditory or visual unisensory target, or a multisensory target, and attention was to be directed to both the visual and auditory modalities. There were no trials in which the cue invalidly predicted the target modality (i.e., after the cue to attend to vision, the target always contained a visual component). Because all attention cues were presented in the visual modality, we cannot exclude the possibility that these cues biased attention towards the visual modality; however previous studies on modality-specific attention have typically utilized visual symbols to cue participants to the target modality (Spence and Driver, 1997; Spence et al., 2001), and unpublished data from our laboratory suggests that any bias is quite small and does not alter the outcome of the task.

This task allows us to investigate responses to unisensory and multisensory stimuli under selective and divided attention conditions. Because there are two components to a multisensory stimulus (an auditory and a visual component), we used a model of statistical facilitation, known as the independent race model (Miller, 1982, 1986), to compare the distribution of multisensory responses to the joint probability of visual and auditory responses. Unlike comparisons of mean RT, this model controls for presence of two stimuli on multisensory trials, and allows us to evaluate multisensory integration, or the speeding of responses to multisensory stimuli. When the probability of responses to multisensory stimuli is significantly greater than the joint probability of responses to unisensory stimuli, this model indicates that multisensory integration has occurred.

To perform this analysis, cumulative distribution functions for each trial type were used to calculate two race distributions for each participant: one for selective attention conditions and one for divided attention conditions. Each participant's multisensory distributions were then subtracted from their race distributions to generate three curves: the first demonstrating the amount of multisensory integration that occurred during selective auditory attention, the second demonstrating the amount of multisensory integration during selective visual attention, and the third showing the amount of multisensory integration during divided attention. Thus, the area under these subtraction curves provides a quantification of the relative amount of multisensory integration occurring in various task conditions. Mean response times are reported in Table 2 for illustrative purposes, but due to the limitations of mean RT data for examining multisensory integration, statistical analyses were performed on area under the curve measures only. The area under the curves was used to perform a $3_{\text{condition}} \times 2_{\text{test session}} \times 2_{\text{group}}$ mixed model ANOVA to determine the impact of the training intervention on multisensory integration in the various attention conditions. Post hoc, paired-samples *t*-tests of pre- to post-training changes for each group were used to further explore the effects of the intervention on integration during each attention condition. Our hypothesis was that attention training would result in reduced multisensory integration during auditory and visual selective attention, but no change in integration during divided attention.

2.4.3. Indirect outcomes

In addition to determining the direct effects of attention training on selective attention and multisensory integration, we also administered several other tests to measure generalization of the intervention to different cognitive domains. Each of these tests was evaluated using a $2_{\text{test session}} \times 2_{\text{group}}$ mixed model ANOVA, and our hypotheses were that pre- to post-training improvements on each test would be larger for the intervention group than for the control group.

The Symbol Digit Modalities Test (SDMT) was used to obtain a measure of general executive function and processing speed that could be normalized for each participant's age and education level (Western Psychological Services, www.wpspublish.com). This test requires participants to pair specific numbers with given geometric figures. Each participant's score was compared to the mean for his or her age and education level, and the average standard deviation from the mean was used in the analysis.

To assess interference during dual-task performance, we used a Walk and Talk paradigm that required participants to complete a 10 m walk, and then to name animals while completing a 10 m walk (adapted from Beauchet et al., 2005).

Table 2
Mean response times on the multisensory integration task by attention/target condition.

	Treatment		Control	
	Pre	Post	Pre	Post
Divided attention				
Unisensory Auditory	782.0 (37.1)	707.0 (21.6)	702.9 (30.0)	685.1 (24.0)
Unisensory Visual	701.9 (30.3)	656.4 (23.6)	646.6 (31.1)	622.4 (22.5)
Multisensory	604.9 (26.5)	581.3 (18.3)	552.1 (23.6)	555.7 (19.9)
Selective auditory attention				
Unisensory Auditory	742.1 (27.4)	710.0 (23.1)	673.7 (22.3)	656.5 (22.8)
Multisensory	591.4 (25.5)	583.1 (20.5)	538.6 (18.1)	534.5 (16.1)
Selective visual attention				
Unisensory Visual	672.9 (24.4)	615.1 (18.4)	604.1 (21.1)	581.4 (19.6)
Multisensory	574.9 (20.9)	566.7 (18.0)	537.8 (19.5)	545.7 (18.7)

Mean response times are presented in ms, with standard error of the mean in parentheses.

An interference effect was calculated as the percent difference between time taken to complete the silent walk and the time taken to complete the walk while naming animals, thus lower interference values indicate that less slowing resulted from the addition of the second task. The number of unique animals named and the interference effect were each entered into the analyses.

To assess working memory, participants completed 1- and 2-back versions of the letter *N*-back task (Braver et al., 1997; Ragland et al., 2002; Owen et al., 2005). In this task, a series of letters is presented one at a time and the participant must indicate whether or not the present item matches the one *N* items back. To assess performance on the 1- and 2-back tasks, we calculated d', a measure of accuracy that controls for response biases using the formula, $d' = Z_{\text{hit}} - Z_{\text{false alarm}}$, where Z_{hit} is the *z*-score for a participant's probability of correctly identifying matching letters, and $Z_{\text{false alarm}}$ is the *z*-score for a participant's probability of incorrectly responding to non-matching letters (Green and Swets, 1966; Macmillan and Creelman, 1991; Klatzky et al., 2008). Higher values of d' indicate better performance on the *N*-back task. Mean d' values for the 1- and 2-back tasks were then analyzed to determine the effects of attention training on working memory task performance.

The Stroop Color-Word test was administered to evaluate interference and executive function (Langenecker et al., 2004). This task requires participants first to name the ink color of a series of non-words (e.g. XXXX, printed in blue ink), then to name the ink color of a series of non-matching color words (e.g. RED, printed in blue ink). An interference effect was calculated as the percent difference between the time taken to answer for the series of non-words and the time taken to respond for the color words. A reduction in the interference effect indicates that less slowing resulted from the incongruent pairing of ink color and written word.

The Trail-Making test was administered to evaluate planning, interference, and executive function (Bowie and Harvey, 2006). Part A of this test requires participants to connect numbered circles in order. Part B of the test requires participants to connect numbers and letters, in an alternating order (1-A-2-B-3-C, etc.). An interference effect was calculated as the percent difference in time taken to complete Parts A and B, and this interference effect was used to analyze performance.

The Hopkins Verbal Learning Test (HVLT; Psychological Assessment Resources, Inc., www.parinc.com) was used to assess verbal learning and memory. This test includes three immediate learning trials, a recognition trial, and a delayed recall trial for a list of 12 common words. The average number of words recalled on the immediate learning trials and the delayed recall trial were each entered into separate analyses. Performance on the recognition trial was calculated using the hit rate minus the false alarm rate, and the hit-false alarm rate was also entered in an analysis.

The Profile of Mood States (POMS; Multi-Health Systems, Inc., www.mhs.com) was administered to evaluate affective states including tension, anger, depression, vigor, fatigue, and confusion. This test requires participants to rate the frequency and intensity of these feelings on a 5-point scale, and responses can be used to calculate a composite score that is used for analysis. Lower scores on this test reflect fewer negative feelings, or a more positive mood state.

The 12-Item Health Status Questionnaire (HSQ-12) was used to assess general physical and emotional health using a series of questions about activities of daily living (Pettit et al., 2001). Higher scores on this test are indicative of better self-reported health. Participants' scores on the physical and emotional subscales were each entered into separate analyses.

All primary, secondary, and indirect outcome evaluations were administered in the same testing session, which lasted for approximately 2.5 h. Tasks were administered in the following order: (1) HVLT; (2) POMS; (3) HSQ-12; (4) SDMT; (5) Trail-Making; (6) Stroop; (7) Walk and Talk; (8) *N*-back; (9–11) Cross-modal Distraction, Within-modality Distraction, and Multisensory Integration were administered in a pseudorandom order, counterbalanced across participants. Each participant completed the evaluation tasks in the same order on their pre- and post-training visits.

3. Results

A modality-specific selective attention training program, designed to promote suppression of background auditory and visual stimuli, was administered to 33 participants. Thirty-three participants were also enrolled in a control educational lecture program. Three participants did not complete the intervention program. Two of these participants had scheduling conflicts arise that prevented them from completing the training and the third was not available for post-training evaluation due to relocation. One participant did not complete the control program due to a change in eligibility, therefore all results are reported for 62 participants ($n = 30$ treatment, $n = 32$ controls). Our retention rates (91% treatment, 97% control) were very good given the commitment level and scheduling obstacles—the study required participants to make 15 visits to the hospital or laboratory over 4 months, many within narrowly proscribed time windows. Nevertheless, all participants answered either "agree" or "strongly agree" to the statements, "Overall, I enjoyed being part of the study" and "I am glad I decided to participate" on a study exit survey.

There were no significant differences in age, education, or MMSE score between the treatment and control groups (Table 1). Participants in the intervention group completed an average of 58 tasks in 119 attempts, progressing on average to the third of five levels of difficulty. Additionally, all participants continued to improve their performance and progress on to increasingly difficult tasks throughout the 8 weeks of attention training. That is, none of the participants reached a point where the required 80% accuracy rate could not be attained after 6 failed attempts on all tasks of a given difficulty level.

We anticipated that completion of the attention training program, relative to the educational lecture control program, would improve participants' ability to ignore irrelevant sensory stimuli, resulting in improved performance on tasks of selective attention, reduced multisensory integration during modality-specific attention, and better functioning in a variety of other cognitive domains because of reductions in interference from background sensory noise. The results from these primary, secondary, and indirect outcome measures are presented below and summarized in Table 3.

On the selective attention task with cross-modal distractors, we analyzed the effects of set size, test session, and training group to determine if the interference associated with the auditory distractors was reduced more by the attention training intervention than by the control program (Fig. 2). The RT data indicated that there was a significant main effect of set size ($F_{1,60} = 24.09$, $p < 0.001$) and a significant session × group interaction ($F_{1,60} = 4.63$, $p < 0.04$, Fig. 2). There were no significant main effects of session or group, and no significant set size × session, set size × group, or set size × session × group interactions (all $F < 1.00$, all $p > 0.40$). The significant session by group interaction confirmed our hypothesis that the training intervention resulted in larger reductions in RT interference than the control program. The

Table 3
Pre- and post-training performance on outcome measures for the treatment and control groups.

		Treatment		Control	
		Pre	Post	Pre	Post
Primary Outcomes					
**	Selective Attention (cross-modal distractors)				
	Set size 2 interference				
	Accuracy (%)	1.1 (5.0)	−0.1 (3.0)	2.1 (6.6)	0.6 (2.7)
	RT (ms)	98.1 (67.0)	66.0 (61.0)	86.5 (61.3)	89.2 (73.4)
	Set size 8 interference				
	Accuracy (%)	13.0 (13.1)	10.2 (17.5)	17.5 (16.0)	7.2 (14.4)
	RT (ms)	157.7 (119.0)	120.3 (113.2)	121.0 (122.7)	153.2 (122.1)
	Selective Attention (within-modality distractors)				
	Set size 2 cost				
	Accuracy (%)	3.7 (8.0)	−0.6 (9.3)	1.7 (5.3)	0.9 (5.2)
	RT (ms)	49.0 (66.7)	64.9 (66.0)	42.6 (72.1)	52.2 (62.8)
	Set size 6 cost				
	Accuracy (%)	−2.0 (8.9)	0.4 (9.7)	−0.5 (10.6)	0.7 (8.1)
	RT (ms)	−2.6 (74.1)	−30.5 (75.9)	15.2 (93.0)	−30.5 (75.9)
Secondary Outcomes					
	Multisensory Integration (area under curve)				
	Divided attention	9.7 (6.9)	8.0 (6.8)	9.8 (6.9)	8.2 (6.3)
**	Selective auditory attention	7.7 (6.2)	4.1 (4.4)	6.3 (5.8)	6.1 (6.5)
**	Selective visual attention	9.6 (8.6)	5.5 (4.5)	6.5 (5.4)	4.9 (4.9)
Indirect Outcomes					
*	1-Back (d')	3.0 (0.7)	3.4 (0.4)	3.1 (0.6)	3.2 (0.7)
	2-Back (d')	2.2 (0.9)	2.6 (0.7)	2.3 (0.8)	2.5 (0.7)
**	SMDT (standard deviation score)	0.0 (0.9)	0.4 (0.8)	0.5 (0.9)	0.6 (0.9)
	Walk & Talk				
**	# of animals named	9.3 (2.3)	10.5 (2.9)	9.5 (2.6)	9.4 (2.1)
	Interference (%)	49.6 (47.9)	55.9 (44.1)	40.1 (30.6)	39.3 (29.0)
	Stroop Color-Word (% interference)	96.7 (25.7)	89.4 (32.0)	89.2 (31.6)	82.8 (31.0)
†	Trail-Making (% interference)	112.4 (56.1)	141.5 (74.4)	122.5 (54.8)	116.3 (37.6)
	HVLT				
	Immediate recall (# of words)	8.1 (1.4)	8.9 (1.6)	8.4 (1.7)	9.4 (1.4)
	Delayed recall (# of words)	8.2 (2.7)	9.0 (1.7)	9.4 (2.4)	9.6 (1.7)
	POMS (composite score)	−0.3 (16.2)	2.8 (16.3)	4.4 (18.0)	3.3 (14.4)
	HSQ-12				
	Physical health score	49.2 (8.8)	48.7 (9.8)	51.0 (7.1)	50.4 (8.3)
	Mental health score	55.3 (8.3)	56.8 (4.4)	54.5 (8.1)	55.5 (4.5)

Summary of mean scores on primary, secondary, and indirect outcome measures, with standard deviation in parentheses. Double asterisks (**) indicate tests on which the treatment group had significantly greater improvements than controls ($p < 0.05$), single asterisk (*) indicates the test on which there was a trend for larger improvements in the treatment group ($p < 0.10$), and the cross (†) indicates the test on which control group had significantly greater improvements than the treatment group ($p < 0.05$).

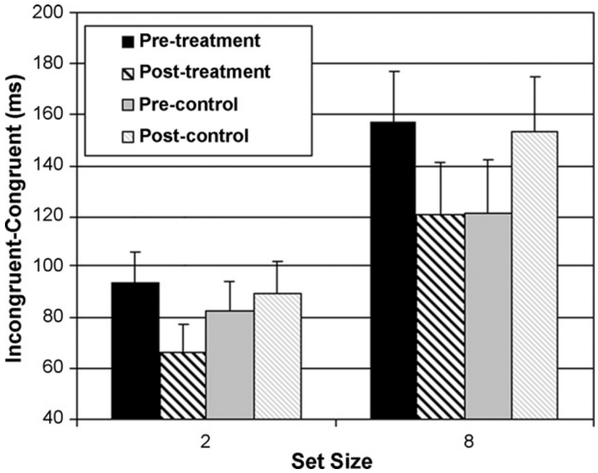

Fig. 2. On a visual attention task with auditory distractors, there was a significant training group by test session interaction ($p < 0.04$), indicating that the treatment group had larger pre- to post-training decreases in interference than controls. This interaction effect was explored using paired-samples *t*-tests examining pre- to post-training changes for each group, and using two-sample *t*-tests to compare differences between the treatment and control group at baseline and after training. These tests indicated that the treatment group showed a trend for reduced interference after training ($p < 0.07$) while the control group had no significant change. Differences between the two groups were not significant before or after training; however, the general trends generated significantly larger decreases in cross-modal distraction for the treatment group than controls. Error bars indicate standard error of the mean.

main effect of set size indicated that both groups had less interference on the easier trials. Importantly, there was no 3-way interaction of set size, session, and group, indicating that the magnitude of improvements experienced by the treatment group was not different across set sizes. To further explore these results, we performed paired-samples *t*-tests for each group, comparing their performance pre- and post-training. We also performed 2-sample *t*-tests to examine the differences between the treatment and control group at baseline and after training. Because training-induced changes for the two groups were not differentially affected by set size, all post hoc analyses were collapsed across set size. These tests indicated that the treatment group showed a trend for reduced interference after training ($t_{29} = 1.90, p < 0.07$) while the control group had no significant change. Comparisons between the two groups indicated that there were also no significant differences between the two groups before or after training. However, the overall trends in interference changes combined to produce significantly larger decreases in cross-modal distraction for the treatment group than controls.

Because the interference effect is due to both speeding of responses on congruent trials versus neutral trials (benefits) and slowing of responses on incongruent trials versus neutral trials (costs), we also examined changes in the RT benefits and costs of cross-modal distractors. The treatment group had reductions in both benefits and costs (mean benefit$_{\text{set size 2\&8}} = -12.8$ ms; mean cost$_{\text{set size 2\&8}} = -22.0$ ms), and the control group had slight increases (mean benefit$_{\text{set size 2\&8}} = 5.8$ ms; mean cost$_{\text{set size 2\&8}} = 11.7$ ms). A $2_{\text{interference type}} \times 2_{\text{set size}} \times 2_{\text{session}} \times 2_{\text{group}}$ ANOVA yielded a significant main effect of interference type ($F_{1,60} = 7.61, p < 0.008$), but no interactions between interference type and the other variables (all $F < 1$, all $p < 0.60$). These results indicated that although benefits contributed more to the overall interference effect than costs, this effect was constant across groups, sessions, and set sizes.

For the accuracy data, there were significant effects of set size ($F_{1,60} = 55.25$, $p < 0.001$) and test session ($F_{1,60} = 8.04$, $p < 0.006$), but no significant effect of training group, and no significant interactions. This indicated that both groups had more interference on difficult trials and that following training, both groups were more accurate on this selective attention task. This finding is consistent with a practice effect for accuracy, but no effect of the training intervention.

Similar analyses performed on the selective attention task with within-modality distractors to investigate the effects of set size, test session, and training group on the performance costs of visual distractors. Participants in both groups had lower RT costs ($F_{1,52} = 42.82$, $p < 0.001$) on trials with high perceptual load (set size 6). However, there were no significant effects of test session or training group on accuracy or response time costs for this task.

Next we investigated multisensory integration to determine if the attention training intervention would reduce integration during modality-specific selective attention. Mean RT for unisensory and multisensory targets in each attention condition are presented in Table 2. To examine the effects of testing session and training group on multisensory integration, we analyzed the area under the curves generated by comparing multisensory and race model response distributions. The ANOVA comparing training-induced changes in multisensory integration during divided attention, selective auditory attention, and selective visual conditions indicated that there was a significant effect of attention condition ($F_{2,120} = 11.50$, $p < 0.001$), a significant effect of test session ($F_{1,60} = 16.48$, $p < 0.001$), no effect of training group, and a trend for an interaction between session and group ($F_{1,60} = 3.55$, $p < 0.06$). As anticipated, these results indicated that there was significantly more integration during divided attention conditions than either selective auditory attention or selective visual attention, and a significant reduction in integration following training (Fig. 3). In paired-samples *t*-tests, the treatment group demonstrated significant reductions in integration during selective auditory ($t_{29} = 3.61$, $p < 0.001$) and selective visual attention ($t_{29} = 3.42$, $p < 0.002$), and no change in integration during divided attention ($t_{29} = 1.36$, $p =$ ns). In contrast, the control group had no significant changes in integration during any attention condition (divided, $t_{31} = 1.14$, $p =$ ns; auditory, $t_{31} = 0.25$, $p =$ ns; visual, $t_{31} = 1.96$, $p =$ ns).

Performance on the SDMT task improved significantly during the second test session ($F_{1,60} = 16.97$, $p < 0.001$), and these improvements in processing speed were greater for the

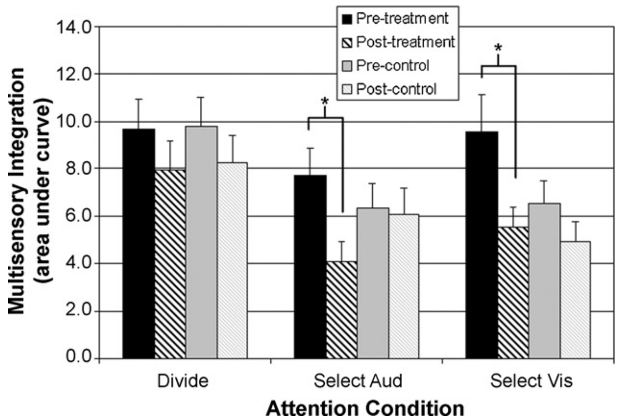

Fig. 3. On an audiovisual integration task, the treatment group demonstrated significant training-induced decreases in multisensory integration during selective auditory attention (paired t-test, $p<0.001$) and selective visual attention (paired t-test, $p<0.002$). There were no significant reductions in integration for the control group. Error bars indicated standard error of the mean.

treatment group than for controls (session × group interaction: $F_{1,60}=6.79$, $p<0.01$).

On the Walk and Talk task, there was a larger increase in the number of animals named during the 10 m walk for the treatment group than controls (session × group interaction: $F_{1,59}=3.88$, $p<0.05$). There was no significant change in dual-task interference, however, to control for differences in walking speed, we used participants' change in walking speed pre- to post-training as a covariate. This analysis indicated that there was still a trend for a larger increase in the number of animals named after attention training than after the control program, even after controlling for any changes in walking speed (session × group interaction: $F_{1,58}=3.25$, $p<0.08$).

Performance on the 1-back working memory task also improved significantly during the second test session ($F_{1,60}=8.68$, $p<0.005$), and although there was no significant effect of group, there was a trend for a session by group interaction ($F_{1,60}=2.71$, $p<0.10$), indicating that there were larger improvements in the treatment group than in the control group. On the 2-back task, performance improved for both groups following training ($F_{1,60}=9.29$, $p<0.003$), and there was no significant effect of training group, and although the interaction trend was similar to that found in the 1-back task, this interaction was not significant. Statistical analyses were performed on d' data in order to account for both hit and false alarm rates; overall accuracy and false alarm rates were as follows: 1-back—Treatment = 94% pre, 97% post; Control = 92% pre, 93% post; 2-back—Treatment = 83% pre, 89% post; Control = 85% pre, 88% post; overall false alarm rates for each group averaged at least 4% on the 1-back task and at least 8% on the 2-back task, and minimum corrections were applied for any subject with 0 false alarms (Macmillan and Creelman, 1991).

On the Stroop Color-Word task, the HVLT test of verbal learning and memory, the POMS mood profile, and the HSQ-12 survey of general health, there were no significant effects of test session or training group, and no significant interactions. On the Trail-Making test, there was a smaller drop in interference after training for the treatment group than for controls, even after controlling for differences in error rates (session × group interaction: $F_{1,58}=4.01$, $p<0.05$). This result was due to the fact that the treatment group improved on both part A and part B of this test, minimizing any change in the interference effect, which represents the difference in performance on parts A and B. In contrast, the control group improved on part B only, producing a significant drop in interference after training.

4. Discussion

Numerous studies in animals and human subjects have demonstrated that the adult mammalian brain retains plasticity, even at advanced ages (Rosenzweig and Bennett, 1996; Colcombe et al., 2004; Bherer et al., 2006; Segovia et al., 2006; Erickson et al., 2007; Mora et al., 2007). This retention of plasticity provides a great opportunity for environmental modification of brain function and behavior. Cognitive training programs that involve repetitive practice on basic cognitive skills, such as memory, reasoning, and speed of processing, have previously been shown to be effective at improving the trained skill, and to a lesser extent, influencing performance on non-trained tasks (Kramer et al., 1995; Jennings et al., 2005; Mahncke et al., 2006; Ball et al., 2007; Rebok et al., 2007). The attention training program detailed in this report provided repetitive, adaptive practice for participants to improve their ability to focus on relevant tasks and to ignore irrelevant, but very salient and distracting stimuli. This intervention was designed to mimic the multisensory nature of the real world, where stimuli from unattended sensory modalities often distracts us, interfering with our performance of tasks such as carrying on a conversation in a busy restaurant, or writing a paper in a noisy laboratory. Because so many perceptual and cognitive processes can be influenced by cross-modal noise, techniques for minimizing the impact of irrelevant stimuli could potentially improve functioning across a variety of domains.

The primary outcome measures for this study were two tasks of visual attention: one that required participants to ignore conflicting auditory distractors, and one that required suppression of conflicting peripheral visual stimuli. Participants who completed 8 weeks of the attention training program had significantly greater reductions in interference from cross-modal distractors than those who completed an educational lecture control program. The treatment group did not, however, show greater improvements than controls at disregarding within-modality distractors during the visual task. These results indicate that this training program is an effective method for minimizing the impact of cross-modal distractors, but does not limit distraction from stimuli within the task modality.

One possible source of these divergent results may be differences in the mechanisms of cross-modal distraction and within-modality distraction. The mechanisms of selective attention within the visual modality have been extensively studied (e.g. Posner and Driver, 1992; Desimone and Duncan, 1995; Kastner and Ungerleider, 2000), and attention to a particular visual stimulus is known to involve several factors. Visual objects must compete for the limited processing resources of the visual system, and attention can bias processing by enhancing neural responses to the attended stimulus, increasing baseline levels of activity in neurons representing the attended location, and also by counteracting the inhibition generated by nearby stimuli (Spitzer et al., 1988; Kastner et al., 1999; Reynolds et al., 1999; Pinsk et al., 2004). Similar processing enhancements during selective attention to particular sounds have also been demonstrated in the auditory system (Woldorff et al., 1993; Grady et al., 1997; Tzourio et al., 1997). Thus, a primary mechanism for attention to a particular feature or location within a sensory modality involves increasing the relevant signal.

In contrast, the primary behavioral impact of focusing attention on one sensory modality and ignoring stimuli in a different modality is not performance enhancements in the attended modality, but rather suppressed processing of stimuli in the unattended modality (Spence and Driver, 1997; Spence et al., 2001). Additionally, a number of imaging studies demonstrate that processing stimuli in one sensory modality results in decreased activity in the other sensory cortices (Kawashima et al., 1995; Kawashima et al., 1999; Laurienti et al., 2002; Johnson and Zatorre, 2005, 2006). These data support the notion that improved information processing during modality-specific attention is through a suppression of cross-modal sensory noise. In addition, although competition for limited processing capacity is a prominent factor in within-modality distraction, it has been demonstrated that attentional resources are not as restricted when processing stimuli in multiple sensory modalities (Duncan et al., 1997; Rees et al., 2001; Talsma et al., 2006). For example Rees et al. (2001) demonstrated that neural activity in response to task-irrelevant visual stimuli was not reduced when the difficulty of an auditory task was increased. In contrast, visual activity corresponding to the task-irrelevant stimuli was attenuated when the difficulty of a concurrent visual task was increased (Rees et al., 2001).

These results indicate that there are different neurophysiological mechanisms at work when attention is engaged to filter out cross-modal distractors and within-modality distractors. These differences in suppressive effects and processing capacity within and between modalities may be differentially modified by training procedures. The training intervention presented here successfully reduced the impact of cross-modal background noise, but did not improve task performance during within-modality distraction. Although this study was not designed to determine which training tasks produced the observed behavioral enhancements, it seems likely that cross-modal training tasks were effective at promoting suppression of cross-modal distraction. Although the within-modality training tasks may also have contributed to improved performance on the evaluation measures, alternative training paradigms may be required to better target the mechanisms of within-modality attention.

Our secondary outcome measure further demonstrated that attention training resulted in reduced susceptibility to the influence of stimuli in the ignored sensory modality. In this task, participants were directed to focus attention on just the auditory or just the visual component of a multisensory stimulus. Following training, the treatment group demonstrated significant reductions in the integration during both selective auditory and selective visual attention conditions, while the control group showed no significant changes in integration. Additionally, there were no changes in integration during divided attention conditions, indicating that the training-induced changes did not represent a global decrease in multisensory integration, but rather a specific decrease in integration when attention is deliberately focused on one sensory modality. This is important for real-world situations, where it may be helpful both for older adults to maintain the benefits gained from congruent multisensory stimuli, and also be able to effectively ignore information in just one sensory modality.

In addition to the training-induced improvements observed in attention and cross-modal suppression, the treatment group also demonstrated improvements on tests of other cognitive functions, including processing speed, dual-task performance, and modest improvements on the 1-back task. One potential source of these transfer effects is improved processing of stimuli in the non-trained tasks due to an increase in signal to noise ratio that results from better suppression of irrelevant cross-modal stimuli. None of the tests used for indirect evaluation were specifically trained; however, the attention training tasks did require speeded manipulations of letters, words, and numbers, and purposeful control of attention. Thus, practice on these elements may have contributed to improvements in the related cognitive domains. Larger trends for improvement on the 1-back versus the 2-back version of this working memory task may be related to the possibility that the training had a larger impact on the maintenance or storage processes thought to be required in the 1-back task, and a smaller effect on the manipulation processes more fully engaged by the 2-back task (Mattay et al., 2006).

In order to determine if participants' progression through attention training could be used to predict their level of improvement on any of the outcome evaluations, we performed a post hoc correlation analysis. This test revealed that there was no significant relationship between the number of training tasks completed or the number of task repeats participants performed during the training sessions and their improvement on any of the outcome measures. This finding indicates that reaching a certain level of difficulty or repeating tasks a specified number of times was not required to produce improvement in the outcome evaluations. Rather, completing 8 h of the training intervention was sufficient to produce significant improvements in the primary, secondary, and several indirect outcomes, regardless of the rate of progression through the training tasks. This promising feature of the intervention program suggests that the intervention program would be helpful for a wide range of ability levels, as participants who repeated many tasks and did not reach the highest levels of difficulty benefited from the training just as much as those who had to repeat few tasks and progressed to the most difficult training tasks.

Attention training did not improve performance on several additional cognitive evaluations, including the Stroop Color-Word test, the Trail-Making test, and the HVLT. Unlike the SDMT, Walk and Talk, and *N*-back tasks, both the Stroop and Trail-Making tests require subjects to resolve conflict and inhibit prepotent responses. These are skills that were never practiced in the training tasks, which always utilized task-irrelevant distractors rather than stimuli that conflicted directly with the task. For example, on a training task where participants were required to sequence numbers, the distractors were everyday scenes or sounds rather than numbers. Training that includes practice suppressing conflicting cross-modal or within-modality distractors may be necessary to promote improvements in these domains, as improvements in modality-specific attention did not impact performance on tasks requiring conflict resolution and response inhibition. Training effects also did not generalize to verbal learning and memory on the HVLT. One possible explanation for this result may be that the HVLT task involves the untimed recall of word list items that have been read to the participant slowly and deliberately by the tester. In this testing situation, modality-specific attention may not affect memory for the list items. In contrast, on timed tasks requiring speeded responses to multiple stimuli such as the SDMT, Walk and Talk, and *N*-back, susceptibility to distracting stimuli can easily impede performance.

One additional point to consider is that although the attention training program detailed in this report successfully improved participants' ability to ignore distracting cross-modal stimuli and enhanced performance in other cognitive domains, all outcome evaluations were conducted in quiet testing rooms. Further testing will be required to determine if these trained skills would generalize to increase performance enhancements on evaluations conducted in a noisier environment, more like the everyday conditions under which demanding cognitive tasks are normally performed.

There were no significant changes in self-reported mood, mental health or physical health status; however, in our very high-functioning and relatively small sample population, changes in these variables may be very difficult to measure. The ACTIVE study found a similar lack of change in such real-world outcomes in very large, but high-functioning intervention groups; however, after a follow-up interval of five years, participants who had completed reasoning training showed significantly less decline than controls on self-reported performance of instrumental activities of daily living such as meal preparation, finance management, and health maintenance (Willis et al., 2006). Further study involving extended follow-up periods, assessment of real-life functioning, and/or lower-functioning participants may be required to detect the impact of this intervention program on functional decline or other clinical measures.

An additional caveat of the small sample size included in this randomized controlled trial is that randomization procedures cannot completely balance baseline performance between the two groups as in large scale trials. However, all analyses utilized a mixed model ANOVA, where the interaction effect was the outcome of interest. Thus, despite the relatively small sample used, we observed training-induced improvements for the intervention group in several cognitive domains that exceeded any improvements demonstrated by the control group. Larger scale follow-up studies will be required to reduce baseline differences between treatment and control groups and to further characterize the effects of the training intervention.

In conclusion, the results of the present study demonstrated that a novel training program targeting modality-specific attention successfully improved healthy older adults' ability to ignore irrelevant cross-modal stimuli. Training also generalized to non-trained cognitive tasks, suggesting that more proficient suppression of background sensory noise can promote performance enhancements on a variety of cognitive tasks. Additional research will be required to determine the potential for reducing age-related functional decline using modality-specific attention training.

Disclosure

Authors J.L.M. and P.J.L., and Wake Forest University School of Medicine are in the process of applying for a patent for the training program described in this manuscript.

Conflict of interest

Authors A.B.L., A.R.M., and M.R.P. have no conflicts of interest to declare.

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