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Enhancing Spatial Attention and Working Memory in Younger and Older Adults

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Abstract

Daily experiences demand both focused and broad allocation of attention for us to interact efficiently with our complex environments. Many types of attention have shown age-related decline, although there is also evidence that such deficits may be remediated with cognitive training. However, spatial attention abilities have shown inconsistent age-related differences, and the extent of potential enhancement of these abilities remains unknown. Here, we assessed spatial attention in both healthy younger and older adults and trained this ability in both age groups for 5 hr over the course of 2 weeks using a custom-made, computerized mobile training application. We compared training-related gains on a spatial attention assessment and spatial working memory task to age-matched controls who engaged in expectancy-matched, active placebo computerized training. Age-related declines in spatial attention abilities were observed regardless of task difficulty. Spatial attention training led to improved focused and distributed attention abilities as well as improved spatial working memory in both younger and older participants. No such improvements were observed in either of the age-matched control groups. Note that these findings were not a function of improvements in simple response time, as basic motoric function did not change after training. Furthermore, when using change in simple response time as a covariate, all findings remained significant. These results suggest that spatial attention training can lead to enhancements in spatial working memory regardless of age.

INTRODUCTION

Spatial attention involves the selective processing of specific stimuli in a given area of the visual field and is typically studied by instructing an individual to selectively attend to upcoming target stimuli based on their predicted location in space (cf. Vecera & Rizzo, 2003). However, as elegantly described by Goodhew, Shen, and Edwards (2016), a number of topics surrounding the spatial extent of attention (e.g., the size of the attentional spotlight, its resolution, distribution within or across the vertical and horizontal meridians) with respect to how broadly an individual can allocate the spatial scope of attention to effectively process stimuli within a relevant location are far from being understood (Goodhew et al.,

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2016; Treisman, 2006; Chong & Treisman, 2005; Ariely, 2001; Greenwood & Parasuraman, 1999; McCalley, Bouwhuis, & Juola, 1995; Eriksen & St James, 1986; Eriksen & Yeh, 1985). Those studies have described two types of attention allocation: focused and distributed spatial attention. Focused attention is engaged when accuracy takes priority over the breadth of the attended visual field, whereas distributed attention faculties are recruited as the relevant attended visual field is expanded (Castiello & Umilta, 1990; Eriksen & St James, 1986).

It has been widely documented that attentional processes degrade with age (Klein, Ponds, Houx, & Jolles, 1997; Cohn, Dustman, & Bradford, 1984; Comalli, Wapner, & Werner, 1962) and that such decline is often associated with impairments in interference control (Clapp, Rubens, Sabharwal, & Gazzaley, 2011). However, it remains unclear how aging affects distributed spatial attention abilities (Zanto & Gazzaley, 2014; Madden, 2007): Some studies have revealed comparable spatial attention abilities in older adults (OA) and younger adults (YA; Langley, Friesen, Saville, & Ciernia, 2011; Madden, 2007; Madden et al., 2007; Tales, Muir, Bayer, & Snowden, 2002; Hartley, Kieley, & Slabach, 1990; Nissen & Corkin, 1985), whereas others have demonstrated age-related impairment in spatial attention performance (Hommel, Li, & Li, 2004; McDowd & Shaw, 2000). Similar discrepancies appear in the literature regarding age-related differences in shifting from narrowly focused attentional allocation to broadly distributed attentional allocation (Mishra & Gazzaley, 2013; Groth & Allen, 2000; Kosslyn, Brown, & Dror, 1999; McCalley et al., 1995; Hartley, Kieley, & McKenzie, 1992). Of note, when age-related sensory and perceptual differences are equated and general age-related slowing has been accounted for, OAs still exhibit deficient attentional modulation of visual cortical activity (Zanto, Hennigan, Ostberg, Clapp, & Gazzaley, 2010).

One of the most common paradigms used to assess spatial selective attention utilizes a spatial cue to indicate where a target will subsequently appear (Posner, 1980). There has been growing evidence using cued paradigms, both peripherally and centrally presented cues, showing that cue-based attentional shifts are preserved in aging (Zanto & Gazzaley, 2014; Tales et al., 2002). However, these null age-related findings are in stark contrast to most of the literature assessing attention and working memory deficits in aging (Zanto & Gazzaley, 2014; Hommel et al., 2004; McDowd & Shaw, 2000), suggesting that this inconsistency may stem from the nuances in the task(s) used to demonstrate this null effect. The inconclusive findings regarding age-related effects on spatial attention may also arise from a lack of control for age-related deficits not specific to attention, such as response time slowing. Alternatively, another possible reason for the null findings may involve how aging affects one’s interpretation of spatial cues, especially when anticipatory cues provide different degrees of information. Previous work has shown that OAs do not utilize anticipatory cues as effectively as their younger counterparts (Zanto & Gazzaley, 2014; Bollinger, Rubens, Masangkay, Kalkstein, & Gazzaley, 2011), suggesting that manipulating the amount of information in an anticipatory cue during a spatial attention task may reveal age-related effects. These findings support the goal of better understanding if and how spatial attention abilities change with age beyond simple age-related differences in response time.

There have been a number of cognitive training studies demonstrating plasticity of attention systems (Montani, De Filippo De Grazia, & Zorzi, 2014; Anguera et al., 2013; MacLean et al., 2010; Tang & Posner, 2009; Jha, Krompinger, & Baime, 2007; Bherer et al., 2005; Green & Bavelier, 2003; Kramer, Larish, & Strayer, 1995). An important example of spatial attention training is the useful field of view (UFOV) training task (Ball, Beard, Roenker, Miller, & Griggs, 1988), which requires attention to be directed at two items simultaneously, thus challenging distributed attention processing (Green & Bavelier, 2006). Previous UFOV training studies suggest that repetitive practicing of this task enhances the size of the effective visual field in OAs (Ball et al., 1988). To advance on these findings, we designed a novel assessment and training approach (distributed attention task [DAT]; Rolle, Voytek, & Gazzaley, 2015) specifically aimed at increasing an individual's ability to more broadly distribute their spatial field of attention. We believe that this type of training aimed at improving one particular cognitive control ability, attention, may engender transfer to another cognitive control ability, working memory, by pushing on common underlying neural circuitry, like in our previous work (Anguera et al., 2013).

Numerous imaging studies have suggested that working memory and spatial attention engage overlapping brain networks (Gazzaley & Nobre, 2012; Naghavi & Nyberg, 2005; Awh & Jonides, 2001; LaBar, Gitelman, Parrish, & Mesulam, 1999), especially when these spatial attention mechanisms are brought online for spatially encoded information (Gazzaley & Nobre, 2012; Silk, Bellgrove, Wrafter, Mattingley, & Cunnington, 2010; Awh & Jonides, 2001). Critically, it is hypothesized that the same prefrontal and parietal regions involved in maintaining an external focus on relevant stimuli could also be recruited to maintain an internal focus on relevant information (Nee & Jonides, 2009). This idea aligns with studies demonstrating that maintaining items in working memory influences the ability to focus one's spatial attention (Lavie & De Fockert, 2005) and vice versa when independently modulating one's attentional or working memory load (Silk et al., 2010).

In light of the growing literature supporting overlapping neural networks underlying attention and working memory processes, it is reasonable that effectively training spatial attention and its neural substrates may lead to transfer toward enhanced working memory. Given that the training task is aimed at strengthening the ability to widely and effectively distribute attention, training may lead to more effective maintenance of cued information in the working memory task, even if it does not directly benefit the binding of objects/features to locations required by change detection task (CDT). Therefore, we hypothesized that a directed distributed attention cognitive training approach would demonstrate beneficial effects on an untrained working memory task. To address this, a working memory task was used here as an assessment of transfer (the CDT; Luck & Vogel, 1997) that relies on the effective retention of spatial information over a delay period.

In this study, we sought to evaluate age-related differences in distributed attention and assess plasticity of this ability in response to cognitive training in both younger and older age groups. To accomplish this, YAs and OAs first completed a novel spatial attention assessment (DAT; Voytek et al., 2017; Rolle et al., 2015) adapted from the Posner cueing task (Posner, 1980) to parametrically manipulate the amount of visual spatial information provided by a pretarget visual cue as well the working memory task. To control for the confound of age-related response time slowing that may contribute to inconclusive findings in the literature regarding spatial attention changes with aging, they also engaged in a simple response time control task to use as a covariate in subsequent analyses. After this, these participants trained on an adaptive version of DAT aimed at expanding the breadth of distribution of their spatial attention.

We hypothesized that both YAs and OAs' performance on DAT assessment would decline as the demand for distributed spatial attention increased (i.e., with less predictive spatial information offered by the cues), such that OAs' performance would show a disproportionately greater decline specifically in the distributed attention trials compared with that of YAs. We further hypothesized that an individual's scope of attentional allocation would increase after training in both age cohorts compared with the placebo control groups, given the evidence that neuroplasticity is evident through older adulthood (for a review, see Park & Bischof, 2013). However, there is less certainty about the direction of the age-related differences in this plasticity. The training gains could be greater for YAs than OAs because of well-documented age-related reductions in plasticity (for a review, see Freitas, Farzan, & Pascual-Leone, 2013). In addition, it has been proposed that the most significant training and transfer effects can occur in high-performance trainees because of the augmentation of previously acquired skills to become even better performers (i.e., the Matthew effect; e.g., Stanovich, 1986; Walberg & Tsai, 1983). However, there is also evidence indicating that OAs are capable of meaningful changes after similar types of interventions (cf. Anguera et al., 2013). Thus, it is possible that YAs might be more optimized in their spatial attention abilities and therefore may not have as much room for improvement because of ceiling effects. In this case, OAs may be better situated to show training-related benefits because their baseline attentional abilities are lower, offering them greater range for improvement. Finally, we hypothesized that spatial attention improvements as a result of training will result in improvements on the untrained spatial working memory task.

METHODS

Participants

All participants were from the San Francisco Bay Area and recruited through online and newspaper advertisements. All participants had normal or corrected-to-normal vision; had no history of stroke, traumatic brain injury, or psychiatric illness; and were not taking psychotropic medication. All participants reported playing less than 2 hr of video games per month. Participants aged 60+ years were characterized as cognitively normal using standard neuropsychological assessment conducted before study initiation. All participants were paid $15/hr for their in-laboratory and at-home participation and gave written informed consent before participation. The study was approved by the committee on human research at the University of California, San Francisco.

Eighty-two healthy, right-handed individuals consented to participate in this study. Forty-two YAs and 40 OAs were randomly assigned to a training group (Train) or an active, expectancy-matched control group (Control; Train YA: $n = 21$, mean age = 23.6 ± 2.8 years, 15 women; Control YA: $n = 21$, mean age = 24.4 ± 3.0 years, 13 women; Train OA: $n= 20$, mean age = 70.1 ± 4.4 years, 15 women; Control OA: *n* = 20, mean age = 67.3 ± 4.5 years, 14 women).

Neuropsychological Battery

All participants 60+ years old completed an 89-question battery probing for potential neurological conditions (e.g., schizophrenia, previous head traumas, stroke) and previous and current use of psychotropic, hormonal, cardiovascular, and cold medications (participants were excluded for current use of psychotropic and thyroid medications) and if there were any physical or mental conditions that may interfere with daily activities (e.g., migraine headaches, substance abuse, neuropathy). Note that most of these tests were specifically designed to assess neurocognitive status in OAs to rule out the presence of mild cognitive impairment. Color blindness was assessed with Ishihara's Tests for Colour Deficiency (Ishihara, 2010). After this initial screening, OA participants were evaluated on two measures probing for cognitive impairments and depression (Mini-Mental State Evaluation [minimum score of 26; Folstein, Folstein, & McHugh, 1975] and Geriatric Depression Scale [Yesavage et al., 1982-1983]) and 13 neuropsychological tests before experimental testing. These 13 tests were subdivided into related domains, and composite scores of each were calculated for each of the following domains:

1. Memory composite: consisted of Logical Memory I (Wechsler, 1987), Symbol Span (Wechsler, 2009), Long-Delay Free Recall measure from the California Verbal Learning Test II (Delis, Kramer, Kaplan, & Ober, 2000), Visual Reproductions I and II (Wechsler, 1987), and Letter Number Sequencing (Wechsler, 2008)
2. Executive Composite: Trail Making Test A and B (Tombaugh, 2004), Delis-Kaplan Executive Function System (D-KEFS), Color-Word Interference Test (Stroop, 1935), Category Fluency (animals; Goodglass, Kaplan, & Barresi, 2001) and Letter Fluency (FAS; Kertesz, 1982), and Wide Range Acievement Test-Reading (Wilkins & Robertson, 2006).
3. Motor evaluation: Grooved Peg Board (Heaton, Grant, & Matthews, 1992; Lewis & Kupke, 1992; Matthews & Klove, 1964)

All individuals were required to be within 2 *SDs* of age-matched controls on at least 12 of 13 neuropsychological tests to be included in the study. This procedure provided a thorough characterization of the cognitive status of each OA participant in multiple domains while simultaneously ensuring that their cognitive faculties were comparable with those of their age-matched peers. All participants tested within 2 *SDs* of the normative values established for each of these measures.

Study Design

We used a double-blinded study design: Data were both collected and analyzed in an anonymized manner by researchers, and participants were blinded to the group assignment after randomization procedure, which was done before the first participant visit to the laboratory. All participants reported to our University of California, San Francisco, laboratory at the Mission Bay Campus before training ("pretraining" session) and after the completion (“posttraining” session) of training (1-week grace period from start/end of training). Participants completed an outcome assessment battery as detailed below at both of these visits to assess training-related cognitive changes. Participants were loaned an iPad 2 tablet (Apple Computer, Inc., 9.7-in. screen size, Wi-Fi enabled, 1024 × 768 screen resolution) for their 2-week training session after their pretraining session and were instructed to train with their assigned task at home for 5 days per week, 30-min training sessions per day, for a maximum of ten 30-min training sessions (5 hr of training in total). All participants were instructed to complete a check-in survey at the start of each training session and a checkout survey at the end of each training session using a custom iPad app that provided us with a secondary measure of training time and compliance. All participants were instructed to train sitting down with the tablet on a flat surface, such as a table, in a location with minimal external distraction. All participant data were locally stored on the iPad and downloaded off of the iPad in the laboratory after their posttraining session.

Assessments

DAT Test—This task, previously described in Rolle et al. (2015) and Voytek et al. (2017), was used to assess each participant’s breadth of spatial attention (from focal to distributed in 25% increments) before and after training. Each trial began with a central cue that indicated the spatial area where a target would appear on an imaginary 360° annulus (see Figure 1). This cue indicated four different levels of information: 100%, 75%, 50%, and 0%: In the 100% level, the exact location of the target was provided; alternatively, during the 0% condition, no information was provided, and thus, the target could appear anywhere on the screen along the annulus. The 75% information cue narrowed the target location to 25% of the screen (90° arc), and the 50% information cue directed attention to half of the screen (180° arc) regarding potential target location. These four information levels (0%, 50%, 75%, and 100%) were used to assess perceptual discrimination performance at a range of attentional allocation challenges, with focal attention assessed as the speed of response on trials cued with 100% information and distributed attention as the speed on trials cued with *0%* information. The 50% and 75% conditions were used to better understand each group’s spatial attention abilities beyond completely distributed and focused conditions. The predictive cue appeared on the screen for 100 msec, and the target appeared on the screen for 50 msec. The SOA was 1750 ± 250 msec. The four cue information levels were randomized to a 25% appearance rate.

On a given trial, the target that appeared in the cued space on the screen was either a go or no-go target. Participants were instructed to keep their eyes fixated on a central fixation cross and their dominant-hand index finger on a “Home” button at the base of the iPad screen throughout the duration of the trial up until the target’s appearance. Upon the appearance of the target (50 msec), participants were instructed to touch the target if it was a green circle (“go” probe) and to not release their finger from the Home button if the target presented was a red circle (“no-go” probe). The interval between cue and target presentation (ISI) was set at 1.2 sec ± 200 msec. Intertrial interval was set at 1500 msec. The fixation cross at the center of the screen served as a gaze fixation point during the trial before target appearance and was also used to provide immediate posttrial feedback to the participant on a trial-by-trial basis by turning red (incorrect) or green (correct) depending on whether they accurately responded.

Our measure of cognitive processing speed, “release time” (RT), was indexed as the time difference between the appearance of the go target and the participant’s initial release from the required holding state at a home position. This response method was implemented based on previous findings with this task demonstrating the sensitivity of RT to the manipulation of predictive cued information (Rolle et al., 2015). The assessment version of DAT (used for pretraining and posttraining testing) included 200 trials (50 trials per information level), and information level presentation was random. Note that this task was used both as an outcome assessment of near-transfer spatial attention abilities and to assess baseline age-related differences in spatial attention abilities before training. To assess training-related changes, the percent change in performance between sessions was calculated as (Posttraining RT — Pretraining RT)/Pretraining RT.

CDT—The CDT, a variation of the Luck and Vogel (1997) task, measures spatial working memory. This task was used as our primary assessment of (far) transfer given that it assesses a distinct type of cognitive control, working memory, relative to what was trained here (see Figure 2). In a given trial, participants were presented with an array of colored squares (150 msec), followed by a retention interval (900 msec), followed by a memory probe consisting of a single colored square. Participants were instructed to identify whether the color of the single square shown in the probe after the retention interval matched the color of the square in that spatial location in the initial memory array. The number of squares shown in the memory array was varied between four set sizes: two-, four-, six-, and eight-item arrays. Participants completed 50 trials of each set size for 200 trials.

Simple Response Time—All participants were assessed on their basic motor speed using a simple target detection task in which they pressed a button on an iPad 2 screen upon the appearance of a red circle at the center of the screen. All participants were instructed to respond as quickly as possible. Average response time (the time between the target appearance and button press) was assayed as a unit of basic motor speed (Hommel et al., 2004). This task was administered to ensure that any training-related enhancements in performance were not attributed to a general motoric speed increase but rather to enhancements in attention processing.

Training Tasks

Participants were randomly assigned to one of the following two training groups:

DAT Training Task—The Posner task has notably been used to make the most progress in the study of spatial attention across the life span by manipulating the type of attention via the use of different cue types (i.e., peripheral and central) and the validity of those cues. To our knowledge, however, no training paradigms have been developed based on the Posner task, and therefore, the ability of training on an adaptive version of this task to induce plasticity of the attention system has been neglected in the literature. To address this limitation, we created a novel training task, DAT, to train plasticity in the spatial allocation of attention in YAs and OAs based on the central cues utilized in the Posner paradigms (see Figure 3). To ensure that the processes being trained were not confounded by extraneous factors, we stripped the complexity of the engagement to only include valid cues. In addition, we manipulated the level of spatial information the cue contained to directly address our research question on the plasticity of distribution of attention and how this changes with age. Specifically, this manipulation allowed us to examine multiple levels of attentional demand, such that, on any given trial, the participant would be required to attend to the entire screen, half the screen, one quarter of the screen, or an exact location on the screen. Finally, we also utilized an adaptive approach for this protocol to create a personalized training experience (Mishra, Anguera, & Gazzaley, 2016; Anguera & Gazzaley, 2015), as this approach has been shown to be a powerful one for cognitive enhancement (Anguera et al., 2013; Mishra & Gazzaley, 2013).

Before training on the DAT task, all participants were thresholded by applying their median RT at the 50% information condition on the DAT test as the initial RT window on the DAT training. An adaptive staircase algorithm continuously titrated the difficulty level to an appropriate level for each participant throughout the training period duration. The task adapted percent-cued information using a two-down/one-up staircase on a trial-by-trial basis; the RT window was reduced by 10 msec as participants successfully proceeded through subsequent rounds of decreasing percentage of predictive information levels in 3% incremental steps. The adaptive algorithm embedded in the paradigm trained both broad distribution of attention as well as focused attention by adapting cued information, pushing each participant to distribute their attention from a focused attentional space toward a complete distribution of attention over the screen. In addition, by reducing the response time window, participants were constantly challenged to more rapidly direct their attention toward the cued space.

Placebo Control Training Task—Participants in the control group trained on Pocket Bowling 3-D HD (Dumadu Games Pvt Ltd, 2011–2013, Bengaluru, Karnataka, India), a virtual bowling game for iPad downloaded through the iTunes App store (see Figure 4). In this game, participants practiced improving their precision in aiming a virtual bowling ball, using their single index finger to knock down as many of the virtual pins as possible. This application was chosen as the control task as it was hypothesized to not demand the same degree of distributed attention-related processes as DAT training.

Training-related Expectancy Ratings—After pretraining testing, participants were introduced to their training tasks: either DAT train or Pocket Bowling 3-D HD (Dumadu Games Pvt Ltd, 2011–2013). Neither the DAT train nor the Pocket Bowling control participants were aware of the other group or the task that they trained with. Both groups were administered the same instructions and brief overview of the goals of the study, namely, to determine if the training game could improve cognitive abilities. Participants then completed a survey measuring their expectations that training with their assigned task would improve various cognitive abilities (Boot, Simons, Stothart, & Stutts, 2013). Participants rated from 1 to 7 on a Likert scale to what extent they felt the paradigm they trained with improved the following cognitive abilities: vision, processing speed, memory, coordination, attention, reasoning, multitasking, cognition, and everyday tasks. For example, participants responded how much they agreed to a statement like, “Training apps like the one I was given to play have the potential to improve memory.” Participants were also asked to rate their engagement by the task and how motivated they were to perform well on the task. The goal of this testing was to confirm that individuals in each training group believed that their assigned intervention would lead to equivalent improvements on the specified outcome measures before training. No significant differences between study groups were found on any measures, and results are presented in Supplemental Materials (http://neuroscape.ucsf.edu/uploads/Rolle_JOCN_2017.pdf).

Statistical Analysis Approach

Simple response time performance was used as a covariate in the ANOVA to control for the effect of age- and training-related response time variance. For the outcome assessments, we examined RT (msec) for each condition (DAT test: 0% information, 50% information, 75% information, and 100% information; CDT: two, four, six, and eight items) at each time point (2; pretraining, posttraining) for each study group (2; train, control) and age cohort (2; OA, YA). First, we examined performance using a Condition × Time × Age group × Study group ANOVA. Follow-up contrasts were performed to further characterize any interactions observed, using a Greenhouse-Geisser correction when assumptions of sphericity were not met. Training data were analyzed as RT (msec) at each training session (10; training sessions) and age cohort (2; OA, YA). Note that, during each training session, participants progressed differentially based on their performance that day on each training (information) condition; thus, we averaged across all information levels for each participant when analyzing the training “improvement” on DAT and CDT (quantified as posttraining — pretraining performance). *t* Tests comparing measures of improvement were done on these “improvement” scores following the stipulated 4 × 2 × 2 × 2 ANOVAs. All averaging was only conducted on correct-response trials. Effect sizes were calculated for all ANOVAs and reported here using partial eta-squared (partial η^2). A post hoc power analysis for each reported effect from the 4 × 2 × 2 × 2 ANOVAs can be found in the Supplemental Materials. Although our focus here was on measures of response time, we report on all outcomes associated with accuracy in the supplemental materials (see Supplemental Tables 1 and 2 here: http://neuroscape.ucsf.edu/uploads/Rolle JOCN_2017.pdf).

RESULTS

Age and Spatial Attention

To examine age-related differences in spatial attention, we focused on comparisons of performance on the pretraining assessment on DAT between age groups. This analysis involved an ANOVA with a within-participant factor of Cue information (0%, 50%, 75%, and 100%) and a between-group factor of Age group (OA, YA). Although we found a main effect of Cue information ($F(3, 204) = 44.84$, $p < .001$) and Age group ($F(1, 68) = 6.46$, $p = .013$), there was no Age group × Cue information interaction ($F(3, 204) = 1.41$, $p = .24$). These results reveal that RT significantly decreases for both groups as the amount of Cue information increases, with YA being significantly faster than OA across all Cue information conditions (see Figure 5) and that OAs exhibit a deficit in spatial attention. Given that these results may reflect inherent motoric slowing with age, we subsequently performed these same analyses as an ANCOVA using simple response time as a covariate. The same pattern of results was observed for the main effect of Age group ($F(1, 65) = 6.63$, $p = .012$), with Cue information showing a similar trend toward significance ($F(1, 65) = 2.35$, $p = .074$), and no Age group × Cue information interaction ($F(3, 195) = 1.34$, $p = .26$), supporting the conclusion that age-related spatial attention deficits were not driven by underlying motoric slowing.

To examine differences in the extremes of focused (the 100% Cue information condition) and distributed (the 0% Cue information condition) attention, we performed an ANCOVA as above with only these Cue information conditions (100% and 0%) acting as within-participant factors. We found a main effect of Cue information ($F(1, 65) = 4.05$, $p = .048$) and Age group ($F(1, 65) = 6.55$, $p = .013$) and again no interaction between Cue information and Age group ($F(1, 65) = 0.094$, $p = .76$). Thus, although OAs were cognitively slower overall in terms of their attention abilities, their focused and distributed attention goals were not differentially affected. This result suggests that DAT training may improve spatial attention abilities equivalently across all information levels in both YAs and OAs.

Motor Speed and At-home Training Results

Simple Response Time—We performed an ANOVA for each Age group using with a within-participant factor of Time (pre, post) and a between-group factor of Study group (train, control) to examine if any of the following training-related findings were due to motoric speed changes. Neither Age group showed a Study group × Time interaction, indicating that response time did not change as a function of training (YA: $F(1, 38) = 2.09$, $p = .15$, partial $\eta^2 = .052$; OA: $F(1, 37) = 1.28$, $p = .26$, partial $\eta^2 = .034$). An independent t test analysis similarly suggested that there was no differential improvement in RT from pretest to posttest time points between the train and control groups for either Age group (YA: $F(35) = 1.59$, $p = .21$; OA: $F(33) = .054$, $p = .25$). Surprisingly, there was no significant difference between OA and YA groups on this test, although they were trending in the anticipated direction ($F(79) = 3.04$, $p = .085$). These results suggest that any Age group differences found in outcome measures cannot be solely attributed to improvements in basic motoric speed.

Spatial Attention during Training—Upon examination of RT across all 10 training sessions, an ANOVA with within-participant factor of Session (10; training sessions) showed a main effect of Session for both OAs ($F(9, 36) = 2.29$, $p = .038$, partial $\eta^2 = .397$) and YAs ($F(9, 63) = 6.01$, $p < .001$, partial $\eta^2 = .364$) but neither an Age group × Session interaction ($F(9, 99) = .57$, $p = .81$) nor a main effect of Age group ($F(1, 11) = .81$, $p = .38$; see Figure 6). As an indication of training-related improvement, both YAs ($t(15) = 4.05$, $p = .004$) and OAs ($t(15) = 2.83$, $p = .03$) showed significant improvement in speed between the first and last training sessions. Age-related RT differences between OAs and YAs in the training groups were present on Days 1–8 of training ($t(31) \geq 2.73$, $p \leq .01$ in each case). Over the last 2 days of training, these Age group differences trended toward significance (although they did not differ; $t(31) \leq 1.87$, $p \geq .073$ on all days; see Figure 6).

Benefits from Training

Spatial Attention—For the analysis of RT effects on the outcome DAT test, we ran a repeated-measures ANOVA (RMANOVA) with two within-participant factors of Cue information (0%, 50%, 75%, and 100%) and Time (pre, post) and two between-participant factors of Study group (train, control) and Age group (OA, YA); further analyses using paired *t* tests to examine the within-session, between-cue information RT comparisons and between-session, within-cue information RT comparisons are included in supplemental materials. There were main effects of Time ($F(1, 66) = 14.42$, $p < .001$, partial $\eta^2 = .179$), Cue information ($F(3, 198) = 91.73$, $p < .001$, partial $\eta^2 = .582$), Study group ($F(1, 66) = 4.07$, $p = .048$, partial $\eta^2 = .058$), and Age group ($F(1, 66) = 11.10$, $p = .001$, partial $\eta^2 = .144$; see Figure 7). Critically, the Time × Study group interaction was significant ($F(1, 66) = 4.90$, $p = .03$, partial $\eta^2 = .069$), suggesting that performance changed differentially between sessions for the train and control groups but that these differences were not modulated by Age group or Cue information. When using the change in simple response time pretraining to posttraining at the individual level as a covariate in the aforementioned ANOVA, all main effects and interactions remained significant, with the exception of the main effects of Time and Study group (Time: $F(1, 66) = 1.84$, $p = .180$, partial $\eta^2 = .028$; Cue information: $F(3, 198) = 3.76$, $p = .012$, partial $\eta^2 = .056$; Study group: $F(1, 66) = 2.20$, $p = .142$, partial $\eta^2 = .034$; Age group: $F(1, 66) = 11.26$, $p = .001$, partial $\eta^2 = .152$; Time × Study group interaction: $F(1, 66) = 5.14$, $p = .027$, partial $\eta^2 = .075$).

Given the lack of interaction with Age group, all subsequent analyses were conducted collapsed across YAs and OAs. We ran paired *t* tests within each Study group to better identify the changes for each Cue information level between time points and whether that differed between Study groups. The train group significantly enhanced their RT performance from pretraining to posttraining time points on all Cue information levels ($t(34) \geq 5.29$, $p \leq .001$ in each case), whereas the control group did not improve ($p \geq .28$ in each case; see Figure 7). An RMANOVA, as above, looking specifically at the comparison of focal (100% Cue information) and distributed (0% Cue information) attention, revealed a significant main effect of Time ($F(1, 31) = 5.12$, $p = .031$) and Cue information ($F(1, 31) = 69.40$, $p < .001$). No other effects or interactions emerged as significant ($F \leq 1.73$, $p \geq .19$ in each case).

Finally, to examine the main effect of Age group on performance, pretraining and posttraining RT was examined for OAs versus YAs. For the train group, OAs were significantly slower than YAs on the 0% cue information condition both at pretraining ($t(33) = 2.27$, $p = .03$) and at posttraining ($t(33) = 3.17$, $p = .003$). There were no significant differences between age groups for the control group at pretraining or posttraining ($t(33) \leq 2.58$, $p \geq .055$ in each case). To further characterize age-related training improvements, for the train group, OA posttraining performance showed trends toward a significant improvement surpassing YA performance at pretraining at each cue information level (0%: $t(33) = 1.51$, $p = .14$; 50%: $t(33) = 1.85$, $p = .073$; 75%: $t(33) = 1.96$, $p = .058$; 100%: $t(33) = 1.90$, $p = .066$). However, for the control group, OAs remained slower on all information conditions at posttraining than YAs at pretraining ($t(33) \geq 1.92$, $p \leq .057$ in all cases).

Spatial Working Memory—For the analysis of response time effects on the CDT, we ran a four-factor RMANOVA with two within-participant factors of Set size (2, 4, 6, 8) and Time (pre, post) and two between-participant factors of Study group (train, control) and Age (OA, YA; see Figure 8). We found main effects of Time ($F(1, 73) = 48.64$, $p < .001$, partial $\eta^2 = .4$), Set size ($F(3, 219) = 65.07$, $p < .001$, partial $\eta^2 = .471$), and Age group ($F(1, 73) = 71.53$, $p < .001$, partial $\eta^2 = .495$). Three Time interactions emerged: Time × Study group ($F(1, 73) = 7.75$, $p = .007$, partial $\eta^2 = .096$), Time × Age group ($F(1, 73) = 9.68$, $p = .003$, partial $\eta^2 = .117$), and Time × Set size ($F(3, 219) = 7.78$, $p < .001$, partial $\eta^2 = .097$). Importantly, the Time × Study group interaction was significant, again suggesting that performance increased between time points in a differential manner for the train group versus the control group. When using the change in simple response time pretraining to posttraining at the individual level as a covariate in the aforementioned ANOVA, all effects remained significant with the exception of the main effects of Time and Set size (Time: $F(1, 73) = .144$, $p = .706$, partial $\eta^2 = .002$; Set size: $F(3, 219) = 1.35$, $p = .257$, partial $\eta^2 = .019$; Age group: $F(1, 73) = 64.27$, $p < .001$, partial $\eta^2 = .482$; Time × Study group: $F(1, 73) = 5.70$, $p = .02$, partial $\eta^2 = .076$; Time × Age group: $F(1, 73) = 6.98$, $p = .02$, partial $\eta^2 = .076$; and Time × Set size: $F(3, 219) = .992$, $p = .397$, partial $\eta^2 = .014$).

Given the main effect and interaction with Age group, we ran subsequent analyses separately for YAs and OAs. Within YAs, we found main effects of Time ($F(1, 33) = 19.95$, $p < .001$, partial $\eta^2 = .377$) and Set size ($F(3, 99) = 21.72$, $p < .001$, partial $\eta^2 = .397$). A Time × Study group ($F(1, 33) = 5.82$, $p = .022$, partial $\eta^2 = .150$) interaction also emerged within the YA group. Using paired t tests to examine training-related improvement between pretraining and posttraining time points, YAs in the train group significantly improved from pretraining to posttraining time points for all set sizes ($t(18) \geq 2.29$, $p \leq .034$ in each case), whereas the control group did not improve on any of the set sizes ($t(15) \leq 0.45$, $p \geq .10$ in each case). Using independent t tests to compare training-related improvement between groups, we found that the train group's improvement exceeded the control group's on the four-, six-, and eight-item set sizes ($t(33) \geq 2.06$, $p \leq .047$ in each case). Interestingly, the train group did not improve more than the control group on the two-item set size ($t(33) = .84$, $p = .40$) but instead on the more difficult set sizes involving at least a four-item memory array.

Within the OA group, we found a main effect of Time ($F(1, 40) = 36.35$, $p < .001$, partial $\eta^2 = .476$) and Set size ($F(3, 120) = 53.46$, $p < .001$, partial $\eta^2 = .572$). Interactions of Time × Study group ($F(1, 40) = 4.33$, $p = .044$, partial $\eta^2 = .098$) and Time × Set size ($F(3, 120) = 6.59$, $p < .001$, partial $\eta^2 = .142$) also emerged. As with the YA group, the Study group × Time interaction for the OA group was significant, suggesting that performance increased between time points differently for each intervention group. Critically, the OA train group's improvement exceeded that of the control group's improvement on the two-, four-, and six-item set sizes ($t(40) \geq 2.02$, $p \leq .05$ in each case). Follow-up t tests revealed that the OA train group improved on all set sizes ($t(21) \geq 3.16$, $p \leq .005$); however, the OA control group improved on the two most difficult set sizes, six and eight items ($t(19) \geq 2.33$, $p \leq .03$), with a trend toward significance on the four-item set size ($p = .064$) and no significant improvement on the two-item set size ($p = .32$). (For an overview of all these results, see Supplemental Table 3, http://neuroscape.ucsf.edu/uploads/Rolle_JOCN_2017.pdf).

Finally, to examine the effect of Age group on performance, RT was examined at pretraining and posttraining time points performance for OAs versus YAs. For the train group, OAs were significantly slower than YAs on all conditions at both pretraining and posttraining test time points ($t(39) \geq 5.01$, $p \leq .001$). For the control group, the OA group was slower than the YA group on all conditions at pretraining or posttraining time points ($t(39) \geq 5.60$, $p \leq .001$ in each case).

DISCUSSION

The present findings reveal that, although spatial attention abilities appear to decline with age, there is no differential decline among focused and distributed attention. Furthermore, spatial attention capabilities are amenable to training-induced improvement regardless of age and unaccounted for by changes in basic motor responses. After training, both younger and older participants demonstrated more efficient target processing for either focused or distributed attention, with transfer of benefits of training gains to improved performance on an untrained measure of spatial working memory. Here, we discuss the implications of these findings in the context of the attention training, aging, and spatial attention literature.

Aging and Spatial Attention

The DAT spatial attention assessment replicated previous findings demonstrating that, the more an individual distributes their attention, the less efficient their processing (i.e., the slower their response to a perceptual decision; Srinivasan, Srivastava, Lohani, & Baijal, 2009; Greenwood & Parasuraman, 1999, 2004; Gottlob & Madden, 1999; Greenwood, Parasuraman, & Alexander, 1997; Hartley et al., 1992; Castiello & Umilta, 1990; Eriksen & St James, 1986). The present results are especially of interest when compared with UFOV findings, which require use of discrimination of a central and peripheral target in the presence of distractions or secondary tasks. On the UFOV task, age-related declines in performance associated with increased distance between targets have been observed (Coeckelbergh, Cornelissen, Brouwer, & Kooijman, 2004; Seiple, Szlyk, Yang, & Holopigian, 1996; Ball et al., 1988; Sekuler & Ball, 1986), indicating a narrower effective visual field compared with younger adults. With respect to aging, the DAT assessment provides further evidence that OAs have a generalized spatial attention deficit, as no selective deficiency was present in the effective allocation of focal versus distributed attention. This is in agreement with work demonstrating that aging leads to less focal spatial attention resources and, consequently, a greater dependence on cues providing location-based information (Greenwood & Parasuraman, 1999, 2004; Greenwood et al., 1997). Such findings are consistent with theories of aging describing greater neural noise (Voytek et al., 2015) or dedifferentiation (Hülür, Ram, Willis, Schaie, & Gerstorf, 2015; Li, Lindenberger, & Sikström, 2001; Li & Lindenberger, 1999) accompanying the aging process, leading to impairments in performance associated with spatial attention and other cognitive control processes.

The present findings are in direct contrast to earlier work indicating that spatial attention faculties are preserved with age (Gottlob & Madden, 1998; Hartley et al., 1990; Nissen & Corkin, 1985). One possible explanation for the discrepancies in these findings may involve the role of the cues: OAs have shown a greater performance benefit on spatial attention tasks when given precise informative cues (Greenwood & Parasuraman, 2004). Nevertheless, tasks with minimally salient cues (i.e., those that are uninformative) that have revealed age-related performance effects have attributed those findings to compromised sensory mechanisms unrelated to attentional processing (Lorenzo-López et al., 2002; Curran, Hills, Patterson, & Strauss, 2001; Yamaguchi, Tsuchiya, & Kobayashi, 1995; Folk & Hoyer, 1992). In this study, the cues did not differentially benefit OAs with respect to either focal or distributed attention, which may reflect aspects of the assessment task itself: a simple target detection task with no distracting stimuli presented; thus, the cues were of limited value. This interpretation is consistent with previous work reporting accentuated aging effects in spatial attention with enhanced task difficulty (Kramer et al., 1995; Dustman & Snyder, 1981). Another reason for these discrepancies could be age-related response time biases. Tasks that rely solely on response time as an outcome do not account for such age-related biases and may simply be reporting on declines in processing speed unrelated to the cognitive processes being probed. Here, the incorporation of a simple response time task in the experimental design to control for this possibility provides further evidence that spatial attention does decline with age, but not differentially between focal versus distributed abilities.

Finally, studies examining cued spatial attention often employ invalid cues to compare with valid cues, with the difference in performance on each acting as an index of spatial attention abilities (Plude, Enns, & Brodeur, 1994). There has been an accumulation of evidence using such paradigms that indicate that spatial attention does not degrade with age (Greenwood, Parasuraman, & Haxby, 1993; Folk & Hoyer, 1992). However, the use of invalid cues during classic Posner-styled designs may be an underlying factor of the absence of age effects, potentially as a result of differential biases across age groups derived from the presence of invalid cues. The DAT paradigm only utilizes valid cues, suggesting that the present characterization of spatial attention is not influenced by individual uncertainty effects associated with invalid cueing.

Spatial Attention Training

Regardless of age, participants who trained with DAT improved their perceptual performance at each cue information level, beyond that of respective age-matched placebo control groups, suggesting that spatial attention resources were generally augmented after training. There was also a pattern of increased speed of response (i.e., RT) across the training period, with OA performance reaching levels of YA on the last 2 days of training. Importantly, there were no simple response time differences between groups after training, suggesting that any observed improvements were not a function of overall motoric speed enhancement.

These training-related results are especially interesting when considered in the context of UFOV training, which has shown task-specific improvements across the life span (Ball et al., 1988). There is one critical difference between this approach and the one implemented here: UFOV training exercises the bounds of one's visual field by presenting a peripheral target at varying distances from the central target. In contrast, DAT uses a constant visual field but modulates the amount of information participants receive about where a cue will appear. In other words, the UFOV training pushes divided attention processes (Sekuler, Bennett, & Mamelak, 2000), whereas the DAT training challenges anticipatory cue processing associated with spatial attention. Another distinction between these tasks is the size of the presentation fields of the platforms used for training (DAT: iPad, UFOV: computer screen), such that any age-related effects on DAT performance are not confounded by age-related deficits in the visual field.

The differences between these spatial attention training approaches are also evidenced by the extent of observed transfer-related effects: UFOV training has not shown transfer to untrained cognitive control abilities, including attention and working memory (Belchior et al., 2013; Roenker, Cissell, Ball, Wadley, & Edwards, 2003; Ball et al., 2002), whereas, here, DAT training led to enhanced performance on an untrained spatial working memory task. Our previous work has demonstrated that an adaptive training protocol that directly challenges cognitive control networks can have benefits that extend to untrained abilities including working memory (Anguera, Gunning, & Arean, 2017; Anguera et al., 2013), which is in agreement with work observing similar transfer-related effects (Mishra, de Villers-Sidani, Merzenich, & Gazzaley, 2014; Craik & Salthouse, 2011; Berry et al., 2010; Zelinski, 2009). Thus, we hypothesized that using a cognitive intervention targeting attention-based processes could lead to a transfer effect on another cognitive control ability, working memory. The transfer effects may reflect the benefit of training anticipation processes as invoked by the adaptivity of the information cue preceding the target in DAT. OAs have been shown to have less beneficial effects from cues informing their expectations, expressed as both diminished behavioral performance and associated anticipatory neural activity when compared with YAs (Pincham, Killikelly, Vuillier, & Power, 2012; Bollinger, Rubens, Masangkay, Kalkstein, & Gazzaley, 2011; Zanto et al., 2011). Thus, the present findings suggest that an adaptive training protocol that puts pressure on anticipation-based processing may have yielded the observed transfer effects.

Interestingly, the YA train group showed significant improvements on the spatial working memory task for the more difficult four-, six-, and eight-item arrays compared with the control group, indicating that training was most beneficial for conditions that demanded greater cognitive control. The OA train group improved on all item arrays; however, the OA control group also showed enhanced performance after training on the most difficult conditions (six and eight items). Given that this result was only present in OA on the most difficult conditions, we suspect this is most likely reflective of a practice effect. This finding is supported by previous work demonstrating heightened practice effects in OAs compared with younger populations (Wais & Gazzaley, 2014; McCarley, Yamani, Kramer, & Mounts, 2012; Becic, Boot, & Kramer, 2008). Importantly, there were no observed training-related basic motoric speed changes from pretraining to posttraining for any of the participants, suggesting that the observed effects were not due to a generalized augmented motoric speed but rather are indicative of training-based plasticity changes in the attention system. In addition, basic motor speed measured by the simple response task was used as a covariate in all analyses to ensure the effects were not a product of response time.

It is important to note that the transfer effect found on the spatial working memory task was for response time and not working memory capacity or accuracy on the task. Although storage-related measures are reflected in capacity scores, the quality of memory can be accurately measured by response time (Pearson, Raskevicius, Bays, Pertzov, & Husain, 2014; Zanto & Gazzaley, 2009). Response time has been used to quantify distinct states of working memory and retrieval speed: early, automatic processing and later, controlled processing (McElree, 1998). McElree suggests that attended information allows for efficient retrieval speeds, whereas representations outside the capacity of focal attention call upon working memory for accuracy and result in slower retrieval speeds. Thus, the coarser the memory representation of an array, the longer the evidence accumulation and corresponding response time take. This proposed pattern of effects was present in the OA and YA train group for spatial working memory at posttraining, as improved retrieval speed indicated an improvement in quality of memory.

There is an abundant literature describing that overlapping networks underlie working memory and attention (Gazzaley & Nobre, 2012; Naghavi & Nyberg, 2005; Awh & Jonides, 2001; LaBar et al., 1999). This suggests that a common mechanism may be responsible for training spatial attention with DAT leading to improvement in spatial working memory, as assessed by the CDT. Beyond sharing overlapping networks, the working memory task relies on key attentional processes that were trained by DAT. The CDT requires the efficient distribution of attention to all areas in one’s spatial field for the retention of positions of the stimuli. Given that we saw training-related improvements across all information conditions, it appears that spatial attention was broadly enhanced by DAT training, not specific to a particular allocation of attention (focused vs. distributed attention). This suggests that participants in the train groups became more effective at allocating their attention in general and therefore were more efficient at detecting the targets within their spatial attention. Because the transfer task relies on an attentional aspect trained by DAT, it is possible that the transfer of benefits from DAT training to the CDT may have been directly due to the strengthening of neural networks underlying spatial attention or as the result of improved spatial working memory maintenance due to the overlap in these mechanisms. Future studies utilizing neural recordings during outcome assessments will help clarify these options.

Limitations

There are a number of important limitations to be noted in the current study. First, this was designed as a feasibility study to determine if there was a signal that spatial attention training can induce transfer of benefits in YAs and OAs to performance improvements in cognitive tasks with overlapping neural mechanisms (i.e., spatial attention to spatial working memory). Follow-up studies driven by the positive findings reported here are planned with a larger number of participants; a greater variety of transfer tasks, including real-world measures; and an assessment of sustainability of effects. The importance of additional measures is emphasized by the only detectable changes reported here being for the response time for both DAT and CDT and not for measures of capacity or accuracy. Moreover, without accompanying neuroimaging to assess the neural mechanisms of the observed training effects, it is not possible to make strong conclusions as to the neural underpinnings of the transfer effects.

Another limitation is that, although we did include a measure of baseline RT to ensure the pre to post differences between study groups were not due to overall changes in speed of response, this assessment measured a different type of response (button push) than the response required by the DAT training (button release). Because of this, it is possible that the baseline RT assessment was not capturing baseline differences in button release speed, which could contribute to differences between groups in pre- to post-DAT performance. However, it should be noted that the responses on the transfer working memory outcome measure, the CDT, also used a standard button press response time, and differential group effects were observed (including, when simple response times were controlled for), suggesting that the use of this task as a control was not a confound in the present work. Another note is that traditional visual screening was not employed for participants here: Such testing would have provided greater control to ensure no group effects were accounted for by differences in acuity. However, we did encourage all participants to use their glasses when using the assigned platforms at their own discretion.

In addition, we are aware that the training task itself could be further optimized to ensure deeper participant engagement via an enhanced delivery system (e.g., a video game implementation: Mishra et al., 2016; Anguera & Gazzaley, 2015). The training time period was rather limited as well; 2 weeks may not be enough time to optimally train attention, as compared with other cognitive training studies that lasted for 4 weeks (Anguera et al., 2013). Although expectancy assessments were utilized to assure that the active control group was an appropriate placebo control, mechanistic interpretations as to the precise active ingredients of the training approach will be strengthened in future studies by better matching of the training and control approaches (e.g., adaptivity and speeded responses demanded by both). Finally, although these expectancy assessments were completed after each participant’s initial exposure to each intervention to control for differences in training-related expectations, we did not perform these same tests posttraining. Because of this, we cannot eliminate the possibility that group differences were not confounded by changes in expectancy that occurred over the course of the study.

Conclusions

Overall, the present findings support the conclusion that, although spatial attention declines with age, it is possible to enhance these processes via adaptive training. Aging leads to generalized deficits in spatial attention allocation without differential age effects for distributed or focal attention. Furthermore, the training effects provide evidence that the effective allocation of attention can be trained and enhanced regardless of age and result in transfer of benefits to a working memory task. Further studies are warranted to understand the neural underpinnings of such effects and elucidate how these behavioral improvements manifest from the strengthening of attentional networks.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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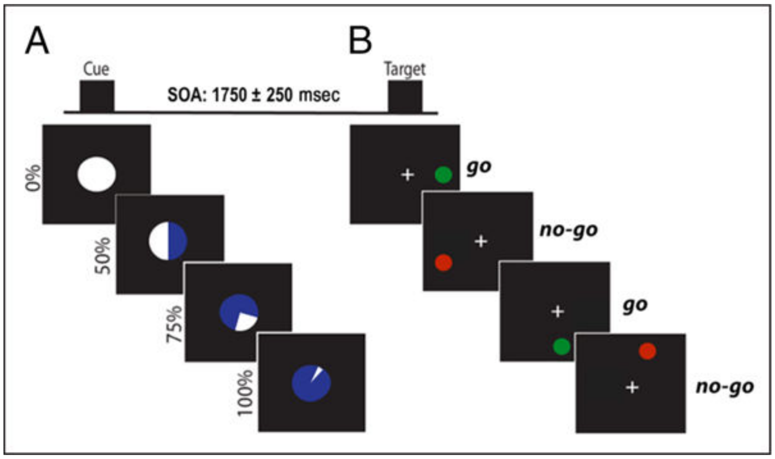

Figure 1.

DAT paradigm. (A) Examples of the central cues, where the white portion of the circle provides information (at the levels 0%, 50%, 75%, and 100%) about where, on an imaginary 360° annulus, the cue will appear on the screen. (B) The participant is presented with either a circular "go" or "no-go" target and is instructed to respond by using their right index finger to tap the green "go" target on the iPad screen and to withhold their response when presented with a red, no-go target.

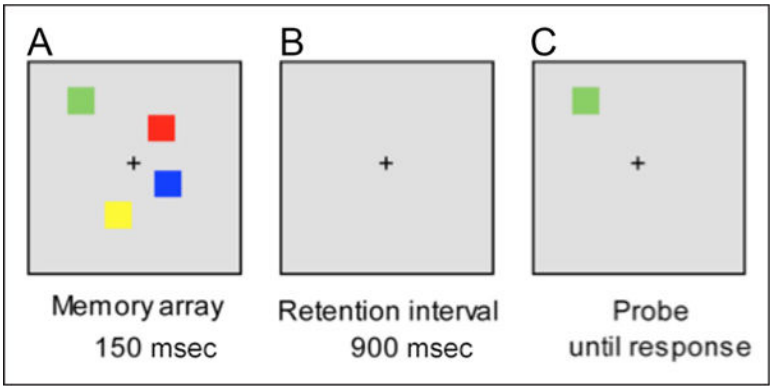

Figure 2.

CDT paradigm. (A) The participant is presented with a memory array consisting of a set of colorful squares (set size of 2, 4, 6, or 8) around a central fixation cross, (B) followed by a retention interval. (C) A single-item memory probe appears in the same spatial location as one of the items from the memory array (A). The participant is instructed to use a keyboard button press to indicate if the probe matches or does not match the corresponding probe from the memory array.

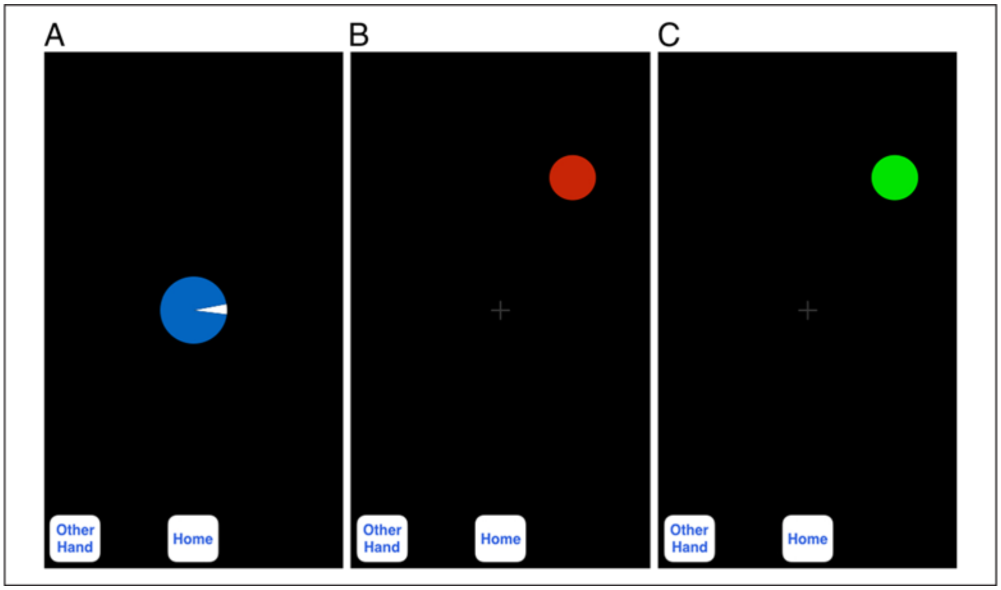

Figure 3.

DAT training. Participants placed their index finger of their nondominant hand on the “other hand” button, while keeping the index finger of their dominant hand on the home button. (A) A spatial cue appearing at the center of the screen indicating the region that a go or no-go target will appear. In the illustrated case, the cue is providing 100% information that the target will appear to the right of the white wedge. (B) Example of a no-go target that participants are instructed to withhold their response to. (C) Example of a go target that participants are instructed to respond to by tapping the target using the index finger that was on the home button.

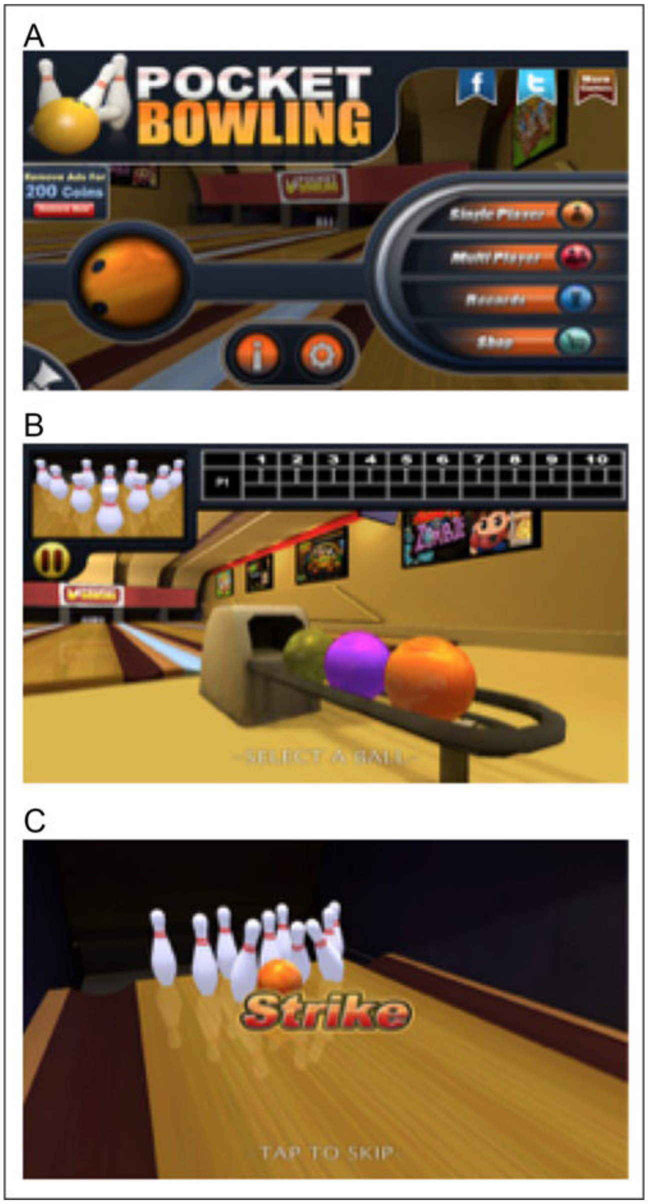

Figure 4.

Pocket Bowling. (A) Control participants trained with singleplayer Pocket Bowling on an iPad as an expectancy-matched placebo control. Participants (B) chose a bowling ball to use and (C) swiped their finger on the screen to “roll” the bowling ball down the aisle toward the pins.

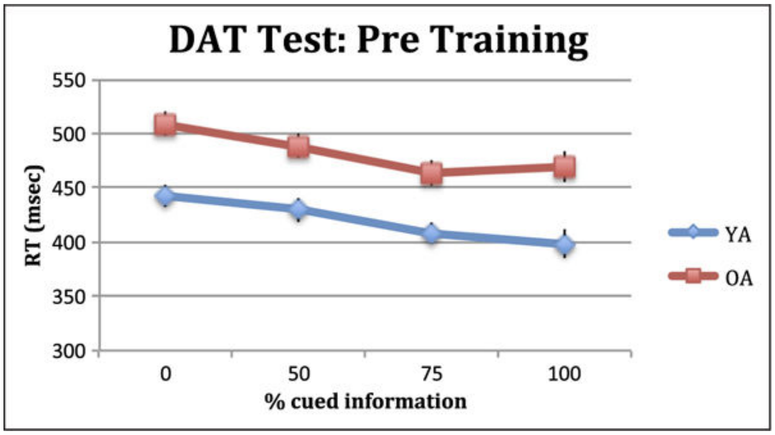

Figure 5.

DAT test at pretraining: For both YAs and OAs, RT significantly decreases as the percentage of cue information increases on the DAT test at pretraining testing ($p < .001$). In addition, YAs perform significantly faster than OAs at every level of cue information ($p = .013$). Error bars represent the standard error.

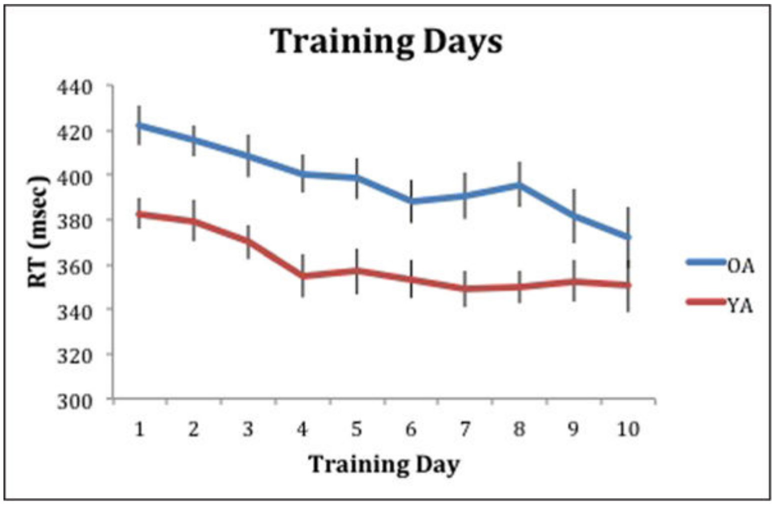

Figure 6.

DAT training; RT averaged across all conditions for OAs and YAs across their 10 days of training. Error bars represent the standard error.

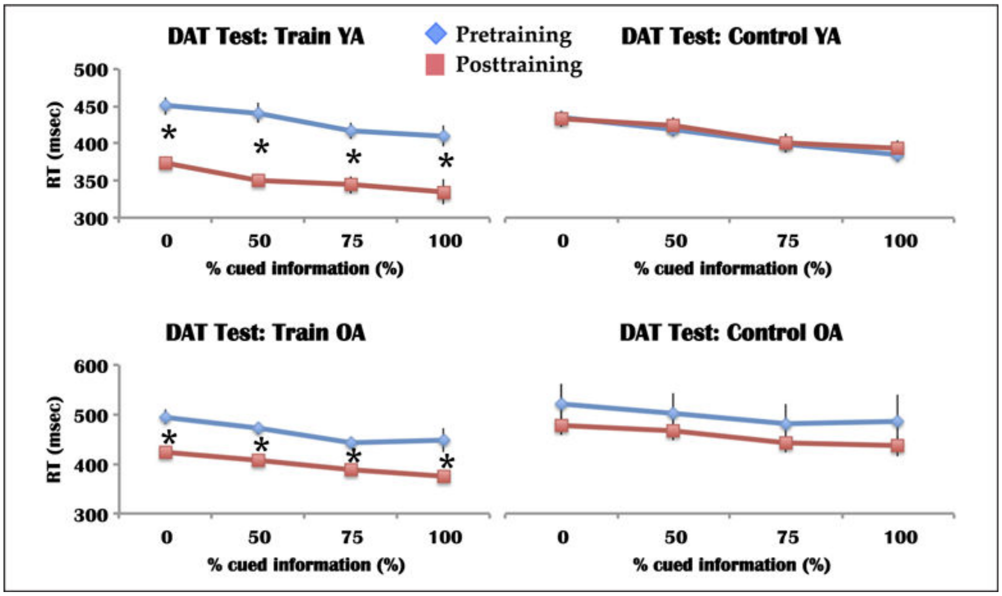

Figure 7.

DAT task. Average RT on DAT test from the pretraining to posttraining sessions split between study and age groups. Both OA and YA train groups showed significant pretraining to posttraining improvements in RT across all conditions, whereas neither OA nor YA control groups showed any session changes. (*$p < .05$ pretraining to posttraining improvement). Control and train groups did not differ in performance at pretraining (YA: $t(35) \leq 1.42$, $p \geq .16$; OA: $t(31) \leq 0.84$, $p \geq .40$ in each case). Error bars represent the standard error.

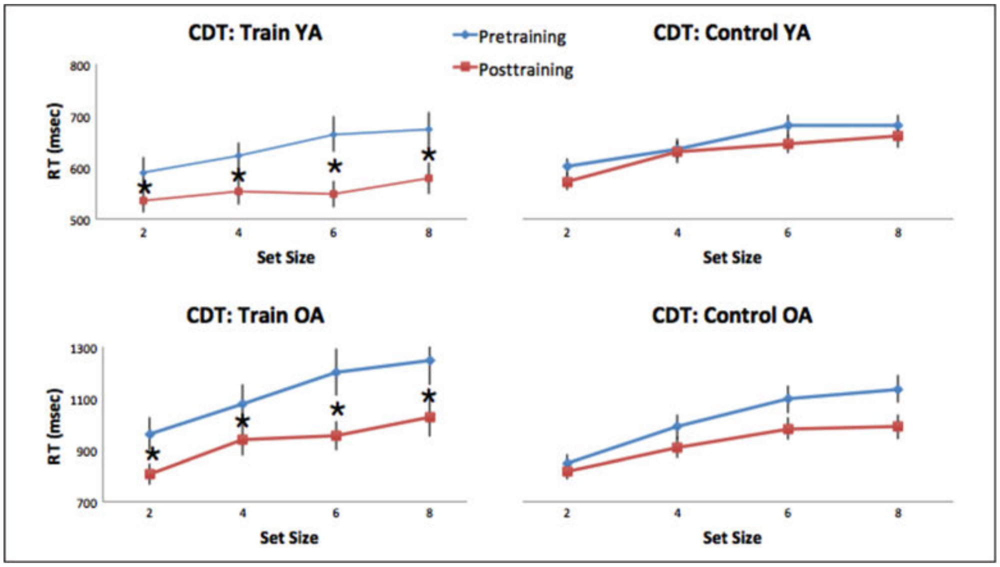

Figure 8.

CDT. Average RT on transfer task CDT from pretraining to posttraining sessions split between study and age groups. Both OA and YA train groups showed pretraining to posttraining improvements in RT across all task conditions. The YA control group showed no session improvement after training; the OA control group showed practice effects for the two more difficult conditions (six and eight items; $*p < .05$ pretraining to posttraining improvement). Control and train groups did not differ in performance at pretraining (YA: $t(35) \leq 0.39$, $p \geq .69$; OA: $t(40) \leq 1.53$, $p \geq .13$ in each case). Error bars represent the standard error.