Cognitive training and selective attention in the aging brain: An electrophysiological study

Jennifer L. O'Brien, Ph.D.*[,a]

Jerri D. Edwards, Ph.D. [b]

Nathan D. Maxfield, Ph.D. [c]

Carol L. Peronto, B.A. [b]

Victoria A. Williams, Au.D. [c]

Jennifer J. Lister, Ph.D. [c]

[a]Department of Psychology, University of South Florida St. Petersburg

[b]School of Aging Studies, University of South Florida; [c]Department of Communication Sciences and Disorders, University of South Florida

*Corresponding Author:

Jennifer L. O'Brien, Ph.D.
jenobrien@usf.edu
140 Seventh Avenue South,
DAV 100
St. Petersburg, Florida 33701
Phone: 1-727-873-4415

Keywords: cognitive intervention, cognitive training, age-related cognitive decline, speed of processing, attention, ERP

Abstract

Objective: Age-related deficits in selective attention are hypothesized to result from decrements in inhibition of task-irrelevant information. Speed of processing (SOP) training is an adaptive cognitive intervention designed to enhance processing speed for attention tasks. The effectiveness of SOP training to improve cognitive and everyday functional performance is well documented. However, underlying mechanisms of these training benefits are unknown.

Methods: Participants completed a visual search task evaluated using event-related potentials (ERPs) before and after 10 weeks of SOP training or no contact. N2pc and P3b components were evaluated to determine SOP training effects on attentional resource allocation and capacity.

Results: Selective attention to a target was enhanced after SOP training compared to no training. N2pc and P3b amplitudes increased after training, reflecting attentional allocation and capacity enhancement, consistent with previous studies demonstrating behavioral improvements in selective attention following SOP training.

Conclusions: Changes in ERPs related to attention allocation and capacity following SOP training support the idea that training leads to cognitive enhancement. Specifically, we provide electrophysiological evidence that SOP training may be successful in counteracting age-related declines in selective attention.

Significance: This study provides important evidence of the underlying mechanisms by which SOP training improves cognitive function in older adults.

Abstract words: 200

Highlights

- The amplitudes of the P3b and N2pc components increased for older adults after behavioral speed of processing (SOP) training.
- This may be associated with enhancement of allocation and capacity of selective attention due to cognitive training.
- The results can be further useful in determining the underlying mechanisms of cognitive training gains and transfer.

1. Introduction

A number of cognitive declines across multiple domains occur with advancing age that negatively affect everyday functioning (e.g., Craik et al., 2000). Selective attention has been shown to be particularly susceptible to age-related declines. Hasher and Zacks (1988) proposed that age-related decreases in selective attention efficiency are due to difficulties in inhibition. As an example, older adults have difficulty suppressing and filtering out task-irrelevant information during the encoding of relevant information into working memory (WM), which can then overload limited WM capacity and decrease ability to retain and manipulate what is relevant. Thus, age-related attentional changes are particularly evident in tasks requiring the suppression of task-irrelevant information (Gazzaley et al., 2005).

Encouragingly, the adult brain appears to have great plasticity, i.e. physical and functional change that results in increased ability to acquire cognitive skills (Jones et al., 2006). There is much evidence that age-related declines in cognitive processes can be reduced or reversed through various forms of cognitive training (for reviews, see Kramer et al., 2002; Lövdén et al., 2010; Lustig et al., 2009). Training-induced plasticity in cognitive function has been demonstrated by using a variety of training methods, including strategy-based training of specific cognitive abilities (i.e., mnemonics for memory or pattern-recognition for reasoning, Ball et al., 2002), and multimodal training of various executive functions (e.g., video game training, Basak et al., 2008). However, transfer of such techniques to untrained tasks or everyday functional abilities has been limited (Lustig et al., 2009).

The focus of the present study is the process-specific approach, a training method for cognitive plasticity that aims to train a processing system at large (usually through perceptual practice) instead of narrowly focusing on implementing strategies to improve performance on a specific task (e.g., mnemonics for memory). Process specific training techniques have resulted in improved selective attention among older adults. For example, Wilkinson and Yang (2011) trained older adults in a Stroop task wherein they had to suppress task-irrelevant stimuli features that were either congruent, incongruent, or unrelated to the task. Interference reaction times (RTs; difference in RT between incongruent and unrelated trials) were shown to significantly decrease across six training sessions, reflecting improved inhibition to distracting information. Because of evidence for transfer of training, the process approach to plasticity training is particularly promising for reversing age-related cognitive and everyday functional decline (Karbach et al., 2010; Lustig et al., 2009).

It is hypothesized (Jonides, 2004) that process-based training targets a certain neural circuit which leads to transfer to other tasks that engage the same or overlapping neural circuit(s), regardless of whether the other tasks were specifically trained. Accordingly, training studies using the process-specific approach have found transfer to untrained tasks (e.g., Berry et al., 2010; Buschkuehl et al., 2008; Dahlin et al., 2008; Edwards et al., 2002; Karbach et al., 2009); whereas other cognitive training approaches do not demonstrate such transfer (Lustig et al., 2009). For further details on how process-based training differs from other approaches, please see Wolinisky et al. (2010) and Lustig et al. (2009).

Speed of processing (SOP) training is one process-based cognitive training method that has shown improved cognitive function (Ball et al., 2007; Vance et al., 2007) as well as far transfer to untrained everyday functional abilities (Ball et al., 2010; Edwards et al., 2009a; Edwards et al., 2009b; Edwards et al., 2002; Edwards et al., 2005b; Wolinsky et al., 2009a; Wolinsky et al., 2009d). SOP training is a computerized, adaptive, cognitive training program aimed at enhancing perceptual processing of visual stimuli in visual attention tasks. SOP training primarily involves practice of perceptual processing with exercise difficulty adapted to the individual user. Several clinical trials have shown that SOP training results in improved speed of processing for visual attention tasks, as measured by performance on the Useful Field of View (UFOV) test (*d*=0.63-2.50) and enhanced allocation of attention as indicated by the Starry Night test (*d*=0.26) (Ball et al., 2007; Vance et al., 2007). UFOV, the primary outcome measure of SOP training, assesses processing speed across four increasingly difficult visual attention tasks (1-visual target identification alone, 2- visual target identification with peripheral target localization, 3- visual target identification with peripheral target localization among distractors, and 4-central target discrimination with peripheral target localization among distractors). Details regarding this well-validated and reliable test can be found elsewhere (Edwards et al., 2006; Edwards et al., 2005a).

SOP training has also transferred to untrained tasks relevant to older adults' everyday lives. For example, SOP training results in more accurate and efficient everyday functional performance as measured by the Timed Instrumental Activities of Daily Living Test (d=0.32, Edwards et al., 2002; Edwards et al., 2005b). SOP training has also resulted in enhanced on-road driving safety (*d*=0.67), reduced at–fault crash risk (*RR*=0.49), and prolonged driving mobility (*d*=0.17-0.23; *OR*=0.59) across three to five years (Ball et al., 2010; Edwards et al., 2009a; Edwards et al., 2009b; Roenker et al., 2003). Other longitudinal benefits of SOP training for older adults include maintained health-related quality of life (*OR*=0.63), and psychological benefits with regard to depression (*OR*=0.62-0.70) and self-efficacy (*OR*=1.39) (Wolinsky et al., 2009a; Wolinsky et al., 2010; Wolinsky et al., 2009b; Wolinsky et al., 2009c; Wolinsky et al., 2006a; Wolinsky et al., 2006b; Wolinsky et al., 2009d; Wolinsky et al., 2009e). However, the underlying neural mechanisms of these training benefits have not been explored.

In the current study, we examined the effects of a new version of SOP training, *Insight*® (Delahunt et al., 2008). This new version was adapted for self-administration by older adults in several ways (for details see, Delahunt et al., 2008) including adding an appropriate user-interface and expanding the exercises to five tasks (see Method for details) with colorful stimuli in a game-like environment. With the goal of exploring the underlying neural manifestations of this efficacious cognitive intervention, we monitored older adults' performance during a visual search task before and after 20 hours of adaptive SOP training. We were specifically interested in the effect of training on the N2pc and P3b components as measures of allocation and capacity of selective attention.

The N2pc is thought to reflect the allocation of attention through visual space during visual search (Hickey et al., 2009; Luck et al., 1997; Luck et al., 1994b; Mazza et al., 2009), wherein attention must be oriented to a salient target among distractors and attentional processing of target stimuli enhanced. The N2pc is a negative-going deflection in the ERP waveform elicited when an attended stimulus is detected in the presence of an array of distractors. It is defined by a more pronounced negative-going activation at posterior electrodes contralateral to the visual hemifield to which the target is presented relative to negative-going activity seen at ipsilateral sites; an effect that peaks in amplitude at approximately 180-300 ms. The N2pc has also been shown to decrease in amplitude with age, reflecting age-related impairment of attentional allocation (Lorenzo-López et al., 2008).

The P3b is thought to reflect the attentional capacity needed for categorization of a target (Donchin, 1981; Kok, 2001; Pfefferbaum et al., 1984). It is a positive-going component that peaks at approximately 300-600 ms following presentation of visual targets, maximally at central and parietal electrode sites. The P3b component is sensitive to target probability, with unexpected or deviant stimuli eliciting a larger P3b than stimuli occurring with a high probability (Donchin, 1981; Kok, 2001). A plethora of studies (e.g., Goodin et al., 1978; Pfefferbaum et al., 1980; Pfefferbaum et al., 1984; Picton et al., 2000; Polich, 1996) have shown that P3b amplitude decreases with age. This well-replicated finding is thought to be indicative of changes in frontal lobe function with age, potentially reflecting a decline in attentional resources (Fabiani et al., 1998; Lorenzo-López et al., 2007).

Recent studies using various types of plasticity-based cognitive training have begun to elucidate the underlying mechanisms by which training can reverse age-related decline in attention (Berry et al., 2010; Buschkuehl et al., 2012; Colcombe et al., 2004; Gazzaley et al., 2005), but electrophysiological evidence for process-based cognitive training methods remains limited. Specifically, it remains unclear how SOP training will impact the amplitudes of the P3b and N2pc components of older adults. As the N2pc reflects the allocation of attentional resources (Luck et al., 1994b) and P3b reflects processing capacity (Donchin, 1981; Kok, 2001), we predicted that if SOP training is successful in counteracting age-related declines in selective attention, we should see an increase in amplitude for both the P3b and N2pc following training.

2. Methods

2.1 Participants

Twenty-two experimentally naïve healthy older adult subjects (11 female, mean age = 71.9, mean years of education = 15.8) participated in exchange for cognitive training. Participants were recruited from a list compiled of older adults who contacted the lab in response to a newspaper article or ad placed in local media. Research received prior approval from the University of South Florida institutional review board. Informed consent was obtained.

2.2 Inclusion and Exclusion Criteria

Participants were required to: be 65 years of age or over, have a Mini-Mental State Examination (Folstein et al., 1975) score of 24 or greater (no severe cognitive impairment or dementia), have no self-reported neurological disorders, have adequate vision (near visual acuity of 20/50 or better, with correction), be a native English speaker, be available and willing to commit to the time requirements of the study, not be concurrently enrolled in another cognitive or training-related study, and not have previously completed a cognitive training program before participating.

2.3 Group Assignment

Training-eligible participants were randomly assigned to a computer-based SOP training group (n=11) or a no-contact control group (n=11). During recruitment, participants were informed that they would be receiving cognitive training either immediately after baseline testing or after a second testing session 10 weeks after their baseline session. Multivariate analysis of variance revealed no significant differences between the groups in age, gender, or education, Wilks' Λ=.867, $F(3,18)=.92$, $p=.451$ (see Table 1).

2.4 Procedure

Participants completed a screening visit to determine eligibility for the study and a baseline assessment EEG was recorded during performance of a visual search task (detailed below). Prior clinical trials of SOP training (e.g., Ball et al., 2007; Edwards et al., 2002; Edwards et al., 2005b) involved 10 hours of practice, with 60-75 minute training sessions conducted twice a week over a 5-week period. Prior study (Delahunt et al., 2009) and our pilot testing indicated that the new program required more time to allow users to navigate through the menus. Thus participants were asked to complete 20 hours of training. After baseline assessment, participants in the cognitive training group worked on computerized training exercises (detailed below) with the goal of completing a minimum of 16 training hours. Training sessions were 70 minutes in duration, 2 days per week, for up to 10 weeks, based on prior study protocols for SOP training (e.g., Ball et al., 2007; Edwards et al., 2002; Edwards et al., 2005b). Individuals were required to take at least one 5-minute break, and were allowed to take additional breaks during the training as necessary. Based on prior findings that the interval between sessions could vary without affecting efficacy (Vance et al., 2007), participants could skip training days if necessary, although frequent or extended missing of sessions was discouraged. Participants were supervised by a trainer in a group computer lab setting. The trainer was present to ensure on-task participation for the full session, as well as to clarify task instructions and handle any technical difficulties if necessary. On average, participants completed 16.6 hours of training (Min=15.3, Max=18.3, SD=0.9). Immediately following training, participants repeated the same visual search task during EEG recording as was completed at baseline.

Participants in the no-contact control group completed a second testing session 10 weeks following their baseline assessment, and were then invited to complete 10 weeks of training. We chose a no-contact control because previous research of SOP training has revealed no differences between no-contact and social- and computer-activity control conditions (Wadley et al., 2006) on behavioral outcome measures.

2.4.1 Visual Search

The visual search paradigm is a very useful method of examining selective attention processes (Luck et al., 1995). In this paradigm, a target stimulus is predefined and occasionally embedded within an array of distractor stimuli and participants search for whether the target is present (oddball stimuli) or absent (frequent stimulus) in each array. During the visual search task, we recorded 64-channel electroencephalogram (EEG) from each participant to obtain event-related potential (ERP) measures of the time course and efficiency of selective attention processing during search. It is important to examine ERP components when studying this type of age-related cognitive decline, as they are sensitive to attentional task demands and provide the excellent temporal resolution necessary to study processes that unfold on a scale of hundreds of milliseconds.

In the visual search task, participants fixated in the center of the screen while detecting the presence of a singleton target stimulus within a multi-element search array. Each array consisted of 14 white car silhouettes on a black background, located within an imaginary rectangle 9.2° x 6.9°of visual angle around a fixation cross. Six cars always appeared in each visual hemifield, and one car appeared above and below fixation (see Figure 1). Three types of arrays were presented: 1) frequent, homogenous, target-absent arrays (all 14 cars identical in size, color, orientation); 2) oddball, target-present arrays containing a singleton “pop-out” target defined by a deviant orientation; and 3) distractor arrays, identical to the frequent array, but with the fixation cross replaced by a multi-pointed star to act as a task-irrelevant distractor. Oddball targets were equally likely to occur in the left versus right hemifield. The visual search task was designed to be parallel in nature with an easily located, “pop-out” target so that participants were able to perform the task quickly and accurately and the ERP components of interest would be elicited on each trial. Distractor arrays were originally included to examine involuntary shifts of attention, which can be elicited by an attention-grabbing task-irrelevant stimulus and measured by the exogenous P3a ERP component. However, the distractor stimulus (multi-pointed star) used in the current task proved to not elicit an automatic, attention switch during search and therefore did not elicit the expected P3a. Thus, responses to this stimulus are excluded from the current analyses.

Each trial began with a fixation cross for a variable duration between 600-900 ms (creating a variable intertrial interval to discourage anticipatory response preparation), followed by a search array for 750 ms during which participants pressed one button for target-present (oddball) trials and one for target-absent (frequent) trials. Participants were instructed to respond as quickly and as accurately as possible. Before beginning EEG recording, participants completed 10-15 trials as practice with the experimenter observing and giving feedback. During recording, RT and accuracy data were collected across 20 blocks of 100 trials each, with 70 homogenous, 15 deviant, and 15 distractor arrays in each block.

2.4.2 Training

The SOP training program consisted of five exercises designed to improve perception, processing speed, attention, and memory. Exercises were embedded in a videogame environment to encourage attention, provide feedback and reward, and improve interest and compliance. Each exercise was adaptive to the participant's performance, with the difficulty of stimulus and task characteristics increasing or decreasing to maintain 85% accuracy as estimated by the ZEST (Zippy Estimation by Sequential Testing) algorithm, a popular maximum likelihood method of adaptive threshold measurement (King-Smith et al., 1994).

The exercises present visual stimuli with a variable interstimulus interval (ISI), and require the user to identify stimulus characteristics or locations. Task difficulty, based on user performance, adapts by adjusting stimulus presentation duration, ISI, stimulus features, and background distinctiveness. Sweep Seeker presents two pairs of moving Gabor patterns in succession, and has participants identify the directions of the movements (see Berry et al., 2010 for more detail). Difficulty increases with increasing spatial frequency of the stimuli. Bird Safari presents participants with a single bird target, which must be located with an array of birds after a delay. Difficulty increases with decreasing target distinctiveness and display times. In Road Tour, participants must identify one of two possible vehicles presented at fixation simultaneously with the location of a road sign presented in the periphery. Difficulty increases with decreasing target distinctiveness and increasing number of peripheral distractors.

Jewel Diver is a multiple-object tracking task, where a variable number of target jewels are presented in a spatial array and then occluded by objects, which then move around the screen for a variable amount of time among other distractor objects. Participants recall which objects occluded targets. Difficulty increases with increase in background distractors, greater speed and longer tracking duration, and decreased background contrast. Master Gardener has participants remember the location and identity of serially presented identical targets (e.g., flowers, leaves) at varying spatial locations and ignore unique distractors presented in the same series. After serial presentation, they identify the location of target presentations. Presentation area, number of potential stimulus locations, number of targets, and ISI all adapt based on performance. A summary of training exercises is presented in Table 2.

2.5 Recording and Analysis

The experiment took place in a dimly lit, sound-attenuating booth. A PC running E-Prime 1.1 (Schneider et al., 2002) recorded behavioral data and presented visual search stimuli on a 43 cm LCD monitor (60 Hz refresh, 1024 × 768 resolution) with a viewing distance of 90 cm. Responses were registered using a push-button response box. Continuous EEG activity was recorded from 64 Ag/AgCl electrodes at standard 10/20 locations in a nylon Quikcap (Neuroscan), with a vertex midline electrode position halfway between Cz and CPz as reference. Four additional electrodes were placed the outer canthus of each eye and on the supra and infraorbital ridges of the left eye to monitor eye movement and blink activity. The EEG was recorded using Neuroscan™ (SCAN version 4.3.1) with a SynAmps2 amplifier and sampled at 500 Hz with a 100 Hz low pass filter (time constant: DC). Electrode impedances were kept below 5 kΩ for most electrodes.

EEG for correct-response trials was separated into epochs of 1050 ms (-300 ms before stimulus onset to 750 ms after). Eye movement artifacts were corrected for each participant by subjecting the EEG data to independent components analysis (ICA), identifying components that match a predefined template and removing these components from each trial if it reduced the overall EEG variance for that trial (see Maxfield et al., 2010 for detailed description of ICA). After ICA correction, channels with fast-average amplitude exceeding 200 μV (large drift) or differential amplitude exceeding 100 μV (high-frequency noise) were marked as bad. For trials with less than 3 bad channels, EEG activity at those channels was replaced using spherical spline interpolation (Ferree, 2000). Any trial with more than three bad channels (5% of the total number of channels) was rejected. No participant lost more than 28% of their trials for any condition, and all but three participants lost well under 10% of their trials per condition due to bad channel artifact. Data were then averaged separately for each stimulus type (frequent, oddball left visual field, oddball right visual field), low-pass filtered at a corner frequency of 40 Hz with a 48 dB/octave roll-off, re-referenced to averaged mastoids, truncated to a critical interval of -200 – 750 ms, and baseline corrected (-200 to 0 ms).

As the goal of the current study was to investigate the potential benefits of SOP training in attentional resource allocation of older adults, we focused our analyses on amplitude measures. N2pc amplitude reflects attentional allocation to a target among distractors (Luck et al., 1994a; 1994b) and P3b amplitude indexes attentional resource capacity during WM updating (Donchin, 1981; Kok, 2001). Both N2pc and P3b latency have been shown to share a positive linear relationship with RT during pop-out visual search (McCarthy et al., 1981; Wolber et al., 2005). In the current study, visual search RTs did not vary as a function of training; therefore we did not include measures of latency for either component.

Following a now-standard approach to isolating N2pc activity from overlapping, spatially nonspecific (bilateral) ERP activity unrelated to shifts of attention, we constructed ‘difference waves’ in which the mean amplitude averaged from arrays containing an ipsilateral target (relative to the electrode location) were subtracted from the average from arrays containing a contralateral target, for each hemisphere separately. Specifically, for the left-hemisphere electrode site, left visual field (LVF) target waveforms were subtracted from waveforms elicited by a target in the right visual field (RVF), and for right-hemisphere electrode site, RVF target waveforms were subtracted from waveforms elicited by a target in the LVF. Since only the N2pc component was lateralized with respect to target hemifield, the use of a difference wave eliminates any bilateral activity that is equally present in both of these waveforms and retains only the lateralized N2pc component (for detailed justifications of this approach, see Girelli et al., 1997; Luck et al., 1994a).

P3b mean amplitude was measured at parietal electrode site Pz for frequent and oddball stimuli (averaged across stimuli in both visual fields) in a 300 – 600 ms poststimulus time window and N2pc mean amplitude was measured for oddball stimuli at posterior electrode sites PO3/4 in a 200 – 400 ms poststimulus time window.

2.6 Analyses

For each component and behavioral effects, an Analysis of Variance (ANOVA) was first used to compare the two conditions at baseline, and repeated-measures ANOVA was used to examine training effects. All tests were two-sided and had an alpha level of .05. The N2pc analysis on oddball trials only included the within-participants factors of Hemisphere (left or right hemisphere electrode site, see above for rationale) and Testing Session (baseline, post), and the between-participants factor of Group (trained, control). A significant Testing Session x Group interaction was expected to support the hypothesis that allocation of selective attention is more efficient after SOP training. Within each subgroup, follow-up paired samples *t*-tests were conducted to examine significant effects. Effects relevant to the proposed hypotheses are summarized below and all main effects and interactions are reported in Table 3.

The P3b analysis included within-participant factors of Testing Session and Stimulus Type, and the between-participants factor of Group. A significant Testing Session x Stimulus Type x Group interaction was expected to support the hypothesis that attentional allocation is enhanced post-training. Within each subgroup, follow-up ANOVAs were conducted to examine significant effects. Effects relevant to the proposed hypotheses are summarized below and all main effects and interactions are reported in Table 4.

Analysis of behavioral performance data accuracy were also conducted using repeated-measures ANOVA to examine training effects, with the within-participant factors of Testing Session and Stimulus Type, and the between-participants factor of Group. We hypothesized there would be no significant interaction between Testing Session and Group due to ease of the task. To further examine this assertion, an ANOVA including Baseline Performance (above or below ceiling) as an additional within-participant factor was conducted to examine moderating effects of baseline performance on training gains. We expected a significant interaction between Baseline Performance, Testing Session, and Group. Within each subgroup, follow-up ANOVAs were conducted to examine significant effects. Effects relevant to the proposed hypotheses are summarized below and all main effects and interactions are reported in Tables 5 and 6.

3. Results

3.1 Electrophysiological results: N2pc

Figure 2 shows separate grand average ERP waveforms for contralateral-minus-ipsilateral differences for the trained and the control groups at both testing points (collapsed across PO3/4 for display purposes only). For both groups, the N2pc component can be seen as a negative-going voltage from approximately 200 – 400 ms post stimulus. ANOVA revealed that initial N2pc amplitudes at baseline (before intervention) did not significantly differ between groups, $F(1,20)=0.11$, $p=.705$, partial $\eta^2=.005$ (see Table 7 for mean amplitudes). Repeated measures ANOVA comparing the two groups across testing sessions indicated a significant Group x Testing Session interaction, $F(1,20)=5.89$, $p=.025$, partial $\eta^2=.227$, reflecting that the mean difference amplitude significantly changed as a function of Group across Testing Sessions. Follow-up paired samples *t*-test analysis within the SOP training condition indicated that increased amplitude from pre to post training occurred for the trained group, $t(10)=4.44$, $p=.001$,. Conversely, a follow-up paired samples *t*-test conducted within the control group did not show a significant increase in amplitude across Testing Sessions after 10 weeks of no contact, $t(10)=-.75$, $p=.470$. For a report of all of the main effects and interactions, please see Table 3[1].

---

[1] Within the N2pc component data, a larger negativity was seen at the left parietal-occipital site PO3, relative to PO4, for both groups at both testing sessions. This lateralized effect was not significantly impacted by the training condition, and thus is not immediately relevant to the current study's findings. A larger N2pc or N2pc-like effect in the left hemisphere is typically found in studies using words as stimuli (e.g., Dell'Acqua et al., 2007; Martin, 1996) but has also been documented in a few studies using non-word visual stimuli (e.g., Hopf et al., 2002; Hopf et al., 2000).

3.2 Electrophysiological results: P3b

Figure 3 shows separate grand average ERP waveforms for frequent and oddball stimuli for the trained and the control groups at both testing points. For both groups, the P3b component can be seen as a positive-going voltage from approximately 300 – 600 ms post stimulus. ANOVA of initial P3b amplitudes at baseline revealed that they did not significantly differ between groups, $F(1,20)=0.01$, $p=.950$, partial $\eta^2<.001$ (see Table 8 for mean amplitudes). Figure 3 illustrates the grand average ERP waveforms of the oddball (target present) and frequent (target absent) stimuli for the trained and control groups at both testing points. The hypothesized interaction between Stimulus Type, Testing Session, and Group was not significant, $F(1,20)=.81$, $p=.378$, partial $\eta^2=.039$; however, there was a significant main effect of Stimulus Type, $F(1,20)=60.23$, $p<.001$, partial $\eta^2=.751$, and a significant interaction between Stimulus Type and Testing Session, $F(1,20)=10.46$, $p=.004$, partial $\eta^2=.343$. Visual analysis of P3b amplitudes for both stimuli types before and after training (see Figure 3) indicated an increase in amplitude to the oddball stimulus after training and a decrease in amplitude to the frequent stimulus for the control group in the second testing session. To investigate whether these opposite changes in P3b amplitude were meaningful, we conducted follow-up ANOVA of Stimulus Type and Testing Session within each trained group separately. Analysis of the trained group showed a significant interaction of Stimulus Type and Testing Session, $F(1,10)=7.21$, $p=.023$, partial $\eta^2=.419$, reflecting a significant increase in P3b amplitude following SOP training. There were no significant changes in amplitude across testing sessions after 10 weeks of no contact for the control group, $F(1,10)=3.34$, $p=.100$, partial $\eta^2=.250$ (for a report of all of the main effects and interactions of the reported analyses, see Table 4).

3.3 Behavioral results

ANOVA of behavioral accuracy performance at baseline revealed that the groups did not significantly differ, $F(1,20)=1.30$, $p=.268$, partial $\eta^2=.061$ (see Table 6 for mean accuracy data). As previously mentioned, the visual search task was designed to be very easy to ensure high accuracy rates to preserve as many trials as possible for the electrophysiological analyses. SOP training was not expected to have a significant impact on pop-out search and therefore we did not expect to see overall differences in the behavioral data based on training Group or Testing Session (see Table 9 for accuracy data). (For a report of all of the main effects and interactions of the reported analyses, see Table 5).

Overall, participants performed the task very well with average accuracy above 85% for all stimuli. However, it is possible that participants who did not perform at ceiling on this task could show training gains. Therefore, we examined whether baseline performance moderated training gains by comparing those who were at ceiling (90%+) and those who were not at ceiling (<90%). By repeating the above analyses with this Baseline Performance variable, we found a significant interaction between Stimulus Type, Testing Session, Baseline Performance, and Group, $F(1,18)=8.13$, $p=.011$, partial $\eta^2=.311$. A follow-up ANOVA of Stimulus Type, Testing Session, and Baseline Performance within the trained group showed a significant three-way interaction, $F(1,9)=9.59$, $p=.013$, partial $\eta^2=.516$, indicating enhanced accuracy post-training for those who did not perform at ceiling. A follow-up ANOVA of Stimulus Type, Testing Session, and Baseline Performance within the control group showed no significant interaction, $F(1, 9)=0.55$, $p=.479$, partial $\eta^2=.057$. (For a report of all of the main effects and interactions of the reported analyses, see Table 6).

4. Discussion

The goal of the current study was to elucidate whether increases in amplitude of the N2pc and P3b ERP components would be observed in older adults as a result of adaptive cognitive SOP training to help determine the underlying mechanisms of gains and transfer. Numerous studies have confirmed that the adult brain is capable of plasticity of cognitive functioning at an advanced age (e.g., Berry et al., 2010; Edwards et al., 2002; Edwards et al., 2005b; Jones et al., 2006). Consistent with this, we provide electrophysiological evidence showing that engaging in adaptive SOP cognitive training can reverse age-related declines in selective attention. We measured older adults' efficiency of selective attention processing during a visual search task by examining the amplitude of two ERP components that have been evidenced to reflect the allocation and capacity of selective attention. After 10 weeks of training, older adults' N2pc and P3b amplitudes significantly increased, but the same increase was not found for an equivalent group of untrained older adults.

The present finding of increased N2pc and P3b amplitudes following SOP training reinforces the hypothesis that there is plasticity in the attentional control and inhibitory systems of older adults. These processes that commonly exhibit age-related decline are shown here to be ameliorated by SOP training. In light of previous findings demonstrating that portions of this training program result in improved cognition and transfer of gains to functional tasks (e.g., Edwards et al., 2002; Edwards et al., 2005b), our results provide preliminary evidence that SOP may particularly be enhancing the allocation and capacity of selective attention, which may account for the positive impact of SOP training on the everyday functioning of older adults.

It is possible that while attentional control efficiency decreases with age, we develop compensatory mechanisms that recruit frontal networks that rely more on top-down processing and thus are less automated. This "compensation" hypothesis (Davis et al., 2008) suggests that, due to age-related decrease in perceptual efficiency, greater top-down cognitive control mediated by the prefrontal cortex is required to compensate for weak attentional control. Continually engaging frontal cortex to maintain representations on line is thought to be an inefficient way to process information and can reflect impaired frontal lobe function (Fabiani et al., 1998). Within this framework, SOP training may reduce dependency on frontally-oriented responses and relocate processing to more posterior regions, thus increasing processing efficiency. It is also possible that training helps older adults recruit more specialized neural mechanisms (“dedifferentiation” hypothesis, (Cabeza, 2002)). Due to the difficulty of inferring the cortical generators of ERP activity based only on the distribution of scalp surface amplitudes (Picton et al., 1995), the current study cannot provide evidence to this end. However, we speculate that enhanced attentional control following SOP training may result in less reliance on frontal function, reducing the frontal consumption of resources and the need for greater top-down cognitive control. Further research investigating the impact of SOP training on shifts of processing from frontal to more posterior regions are necessary to fully elucidate this possibility.

Many clinical trials have evidenced transfer of SOP training to cognitive and everyday function, but the underlying neural mechanisms have not been determined. Our findings are the first step in elucidating potential underlying neural changes associated with SOP training gains and transfer. In addition to yielding important electrophysiological information related to the underlying neural mechanisms of training-based cognitive enhancement, this ERP study provides further support for the previously reported behavioral improvements in selective attention (Ball et al., 2002; Edwards et al., 2005b) and inhibitory mechanisms (Mozolic et al., 2011) after cognitive training.

It is important to note that larger training effects could possibly be found with more difficult behavioral tasks. Although we did not find overall training effects in the behavioral visual search task, results indicated that this could be attributed to ceiling performance at baseline. Those in the training group who did not perform at ceiling did improve pre- to post- training in accuracy, while equivalent controls did not. As previously mentioned, visual search RTs did not vary as a function of training; and we therefore we did not include measures of latency for either component. In addition to the behavioral task not being challenging, our sample size was also small. Thus, further research should examine whether reaction time or latency are improved from SOP training among a larger sample, with a more difficult behavioral task. In future studies, a more challenging behavioral task can be used to help uncover other mechanisms of training-induced cognitive change, such as speed of processing.

In the current experiment, participants were required to search through an array of distractors to locate a pre-defined target, which was infrequently present throughout the experiment. Successful completion of this task involved directing attention toward task-relevant stimuli and inhibiting task-irrelevant information. Both of these processes are known to decline with age, but the current study shows that electrophysiological markers of selective attention allocation and capacity can be enhanced after cognitive training. The current results may help define the underlying mechanisms by which training can reverse age-related decline in selective attention control. This study gives evidence to help validate the use of non-invasive, non-pharmacological behavioral strategy of cognitive training to reverse age-related cognitive decline.

Disclosure Statement

Dr. Edwards served as a limited consultant to Posit Science Inc. in June-August of 2007. There are no other potential or actual conflicts of interest to report.

References

Ball K, Berch DB, Helmers KF, Jobe JB, Leveck MD, Marsiske M, et al. Effects of cognitive training interventions with older adults. JAMA 2002;288:2271-2281.

Ball K, Edwards JD, Ross LA. The impact of speed of processing training on cognitive and everyday functions. J Gerontol B Psychol Sci Soc Sci 2007;62:19-31.

Ball K, Edwards JD, Ross LA, McGwin JG. Cognitive training decreases motor vehicle collision involvement of older drivers. J Am Geriatr Soc 2010;58:2107-2113.

Basak C, Boot WR, Voss MW, Kramer AF. Can training in a real-time strategy video game attenuate cognitive decline in older adults? Psychol Aging 2008;23:765-777.

Berry AS, Zanto TP, Clapp WC, Hardy JL, Delahunt PB, Mahncke HW, et al. The influence of perceptual training on working memory in older adults. PLoS ONE 2010;5:e11537.

Buschkuehl M, Jaeggi SM, Hutchison S, Perrig-Chiello P, Däpp C, Müller M, et al. Impact of working memory training on memory performance in old-old adults. Psychol Aging 2008;23:743-753.

Buschkuehl M, Jaeggi SM, Jonides J. Neuronal effects following working memory training. Dev Cogn Neurosci 2012;2:S167-S179.

Cabeza R. Hemispheric asymmetry reduction in older adults: The HAROLD model. Psychol Aging 2002;17:85-100.

Colcombe S, Kramer AF, Erickson KI, Scalf P, McAuley E, Cohen NJ, et al. Cardiovascular fitness, cortical plasticity, and aging. Proc Natl Acad Sci U S A 2004;101:3316-3321.

Craik F, Salthouse T. Handbook of aging and cognition II. Mahwah: Erlbaum; 2000.

Dahlin E, Neely AS, Larsson A, Bäckman L, Nyberg L. Transfer of learning after updating training mediated by the striatum. Science 2008;320:1510-1512.

Davis SW, Dennis NA, Daselaar SM, Fleck MS, Cabeza R. Qué PASA? The posterior–anterior shift in aging. Cereb Cortex 2008;18:1201-1209.

Delahunt PB, Ball KK, Roenker DL, Tinker DE, Hardy JL, Mahncke HW. Evolution of useful field of view training. San Francisco: Posit Science; 2009.

Delahunt PB, Hardy JL, Brenner DF, Chan SC, Dewey JA, Mahncke H, et al. InSight: Scientific principles of a brain-plasticity-based visual training program. San Francisco, CA: Posit Science Corporation; 2008.

Dell'Acqua R, Pesciarelli F, Jolicœur P, Eimer M, Peressotti F. The interdependence of spatial attention and lexical access as revealed by early asymmetries in occipito-parietal ERP activity. Psychophysiology 2007;44:436-443.

Donchin E. Surprise! Surprise? Presidential Address. Psychophysiology 1981;18:493-513.

Edwards JD, Delahunt PB, Mahncke HW. Cognitive speed of processing training delays driving cessation. J Gerontol A Biol Sci Med Sci 2009a;64A:1262-1267.

Edwards JD, Myers C, Ross LA, Roenker DL, Cissell GM, McLaughlin AM, et al. The longitudinal impact of cognitive speed of processing training on driving mobility. The Gerontologist 2009b;49:485-494.

Edwards JD, Ross LA, Wadley VG, Clay OJ, Crowe M, Roenker DL, et al. The useful field of view test: Normative data for older adults. Arch Clin Neuropsych 2006;21:275-286.

Edwards JD, Vance DE, Wadley VG, Cissell GM, Roenker DL, Ball KK. The reliability and validity of the Useful Field of View Test as administered by personal computer. J Clin Exp Neuropsychol 2005a;27:529-543.

Edwards JD, Wadley VG, Myers RS, Roenker DL, Cissell GM, Ball KK. Transfer of a speed of processing intervention to near and far cognitive functions. Gerontology 2002;48:329-340.

Edwards JD, Wadley VG, Vance DE, Wood K, Roenker DL, Ball KK. The impact of speed of processing training on cognitive and everyday performance. Aging Ment Health 2005b;9:262-271.

Fabiani M, Friedman D, Cheng JC. Individual differences in P3 scalp distribution in older adults, and their relationship to frontal lobe function. Psychophysiology 1998;35:698-708.

Ferree T. Spline interpolation of the scalp EEG. Technical report, Electrical Geodesics, Inc; 2000.

Folstein MF, Folstein SE, McHugh PR. "Mini-mental state": A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res 1975;12:189-198.

Gazzaley A, Cooney JW, Rissman J, D'Esposito M. Top-down suppression deficit underlies working memory impairment in normal aging. Nat Neurosci 2005;8:1298-1300.

Girelli M, Luck SJ. Are the same attentional mechanisms used to detect visual search targets defined by color, orientation, and motion? J Cogn Neurosci 1997;9:238-253.

Goodin D, Squires K, Henderson B, Starr A. Age-related variations in evoked potentials to auditory stimuli in normal human subjects. Electroencephalogr Clin Neurophysiol 1978;44:447-458.

Hasher L, Zacks RT. Working memory, comprehension, and aging: A review and a new view. In: Bower GH, editor. The psychology of learning and motivation. New York: Academic Press.; 1988. p. 193-225.

Hickey C, Di Lollo V, McDonald JJ. Electrophysiological indices of target and distractor processing in visual search. J Cogn Neurosci 2009;21:760-775.

Hopf JM, Boelmans K, Schoenfeld AM, Heinze HJ, Luck SJ. How does attention attenuate target–distractor interference in vision?: Evidence from magnetoencephalographic recordings. Brain Res Cogn Brain Res 2002;15:17-29.

Hopf JM, Mangun GR. Shifting visual attention in space: an electrophysiological analysis using high spatial resolution mapping. Clin Neurophysiol 2000;111:1241-1257.

Jones S, Nyberg L, Sandblom J, Stigsdotter Neely A, Ingvar M, Magnus Petersson K, et al. Cognitive and neural plasticity in aging: General and task-specific limitations. Neurosci Biobehav Rev 2006;30:864-871.

Jonides J. How does practice makes perfect? Nat Neurosci 2004;7:10-11.

Karbach J, Kray J. How useful is executive control training? Age differences in near and far transfer of task-switching training. Dev Sci 2009;12:978-990.

Karbach J, Mang S, Kray J. Transfer of task-switching training in older age: The role of verbal processes. Psychol Aging 2010;25:677-683.

King-Smith PE, Grigsby SS, VIngrys AJ, Benes SC, Supowit A. Efficient and unbiased modifications of the QUEST threshold method: Theory, simulations, experimental evaluation and practical implementation. Vision Res 1994;34:885-912.

Kok A. On the utility of P3 amplitude as a measure of processing capacity. Psychophysiology 2001;38:557-577.

Kramer AF, Willis SL. Enhancing the cognitive vitality of older adults. Curr Dir Psychol Sci 2002;11:173-177.

Lorenzo-López L, Amenedo E, Cadaveira F. Feature processing during visual search in normal aging: Electrophysiological evidence. Neurobiol Aging 2008;29:1101-1110.

Lorenzo-López L, Amenedo E, Pazo-Álvarez P, Cadaveira F. Visual target processing in high- and low-performing older subjects indexed by P3 component. Clin Neurophysiol 2007;37:53-61.

Lövdén M, Bäckman L, Lindenberger U, Schaefer S, Schmiedek F. A theoretical framework for the study of adult cognitive plasticity. Psychol Bull 2010;136:659-676.

Luck SJ, Girelli M, McDermott MT, Ford MA. Bridging the gap between monkey neurophysiology and human perception: An ambiguity resolution theory of visual selective attention. Cognit Psychol 1997;33:64-87.

Luck SJ, Hillyard SA. Electrophysiological correlates of feature analysis during visual search. Psychophysiology 1994a;31:291-308.

Luck SJ, Hillyard SA. Spatial filtering during visual search: Evidence from human electrophysiology. J Exp Psychol Hum Percept Perform 1994b;20:1000-1014.

Luck SJ, Hillyard SA. The role of attention in feature detection and conjunction discrimination: An electrophysiological analysis. Int J Neurosci 1995;80:281-297.

Lustig C, Shah P, Seidler R, Reuter-Lorenz P. Aging, training, and the brain: A review and future directions. Neuropsychol Rev 2009;19:504-522.

Martin E. The N2pc component as an indicator of attentional selectivity. Electroencephalogr Clin Neurophysiol 1996;99:225-234.

Maxfield ND, Huffman JL, Frisch SA, Hinckley JJ. Neural correlates of semantic activation spreading on the path to picture naming in adults who stutter. Clin Neurophysiol 2010;121:1447-1463.

Mazza V, Turatto M, Caramazza A. Attention selection, distractor suppression and N2pc. Cortex 2009;45:879-890.

McCarthy G, Donchin E. A metric of thought: A comparison of P300 latency and reaction time. Science 1981;211:77-80.

Mozolic JL, Long AB, Morgan AR, Rawley-Payne M, Laurienti PJ. A cognitive training intervention improves modality-specific attention in a randomized controlled trial of healthy older adults. Neurobiol Aging 2011;32:655-668.

Pfefferbaum A, Ford J, Walton R, Kopell B. Age differences in P3-reaction time associations. Electroencephalogr Clin Neurophysiol 1980;49:257-265.

Pfefferbaum A, Ford J, Wenegrat B, Roth W, Kopell B. Clinical application of the P3 component of event-related potentials. Electroencephalogr Clin Neurophysiol 1984;59:85-103.

Picton T, Bentin S, Berg P, Donchin E, Hillyard SA, Johnson RJ, et al. Guidelines for using human event-related potentials to study cognition: Recording standards and publication criteria. Psychophysiology 2000;37:127-152.

Picton T, Lins O, Scherg M. The recording and analysis of event-related potentials. In: Boller F, Grafman J, Johnson RJ, editors. Handbook of neuropsychology. Amsterdam: Elseiver; 1995. p. 3-73.

Polich J. Meta-analysis of P300 normative aging studies. Psychophysiology 1996;33:334-353.

Roenker DL, Cissell GM, Ball KK, Wadley VG, Edwards JD. Speed-of-processing and driving simulator training result in improved driving performance. Hum Factors 2003;45:218-233.

Schneider W, Eschman A, Zuccolotto A. EPrime user's guide. Pittsburgh, PA: Psychology Software Tools, Inc.; 2002.

Vance D, Dawson J, Wadley V, Edwards J, Roenker D, Rizzo M, et al. The accelerate study: The longitudinal effect of speed of processing training on cognitive performance of older adults. Rehabil Psychol 2007;52:89-96.

Wadley VG, Benz RL, Ball KK, Roenker DL, Edwards JD, Vance DE. Development and evaluation of home-based speed-of-processing training for older adults. Arch Phys Med Rehabil 2006;87:757-763.

Wilkinson A, Yang L. Practice-oriented retest learning as the basic form of cognitive plasticity of the aging brain. J Aging Res 2011;2011:407074.

Wolber M, Wascher E. The poster contralateral negativity as a temporal indicator of visuo-spatial processing. J Psychophysiol 2005;19:182-194.

Wolinsky F, Mahncke H, Kosinski M, Unverzagt F, Smith D, Jones R, et al. The ACTIVE cognitive training trial and predicted medical expenditures. BMC Health Serv Res 2009a;9:109.

Wolinsky FD, Mahncke HW, Vander Weg MW, Martin R, Unverzagt FW, Ball KK, et al. Speed of processing training protects self-rated health in older adults: enduring effects observed in the multi-site ACTIVE randomized trial. Int Psychogeriatr 2010;22:470-478.

Wolinsky FD, Mahncke HW, Vander Weg MW, Martin R, Unverzagt FW, Jones RN, et al. The effect of speed-of-processing training on depressive symptoms in ACTIVE. J Gerontol B Psychol Sci Soc Sci 2009b;64A:468-472.

Wolinsky FD, Mahncke HW, Weg MWV, Martin R, Unverzagt FW, Ball KK, et al. The ACTIVE cognitive training interventions and the onset of and recovery from suspected clinical depression. J Gerontol B Psychol Sci Soc Sci 2009c;64B:577-585.

Wolinsky FD, Unverzagt FW, Smith DM, Jones R, Wright E, Tennstetdt SL. The effects of the ACTIVE cognitive training trial on clinically relevant declines in health-related quality of life. J Gerontol A Biol Sci Med Sci 2006a;61B:S281-S287.

Wolinsky FD, Unverzagt FW, Smith DM, Jones RN, Stoddard AM, Tennstedt SL. The ACTIVE cognitive training trial and health-related quality of life: Protection that lasts for 5 years. J Gerontol A Biol Sci Med Sci 2006b;61:1324-1329.

Wolinsky FD, Vander Weg MW, Martin R, Unverzagt FW, Ball KK, Jones RN, et al. The effect of speed-of-processing training on depressive symptoms in ACTIVE. J Gerontol A Biol Sci Med Sci 2009d;64A:468-472.

Wolinsky FD, Vander Weg MW, Martin R, Unverzagt FW, Willis SL, Marsiske M, et al. Does cognitive training improve internal locus of control among older adults? J Gerontol B Psychol Sci Soc Sci 2009e;65B:1-8.