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Partial maintenance of auditory-based cognitive training benefits in older adults

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ABSTRACT

The potential for short-term training to improve cognitive and sensory functions in older adults has captured the public's interest. Initial results have been promising. For example, eight weeks of auditory-based cognitive training decreases peak latencies and peak variability in neural responses to speech presented in a background of noise and instills gains in speed of processing, speech-in-noise recognition, and short-term memory in older adults. But while previous studies have demonstrated short-term plasticity in older adults, we must consider the long-term maintenance of training gains. To evaluate training maintenance, we invited participants from an earlier training study to return for follow-up testing six months after the completion of training. We found that improvements in response peak timing to speech in noise and speed of processing were maintained, but the participants did not maintain speech-in-noise recognition or memory gains. Future studies should consider factors that are important for training maintenance, including the nature of the training, compliance with the training schedule, and the need for booster sessions after the completion of primary training.

1. Introduction

In response to growing interest in the potential for training to remediate perceptual and cognitive deficits (Pichora-Fuller & Levitt, 2012), software developers have marketed a wide variety of training programs to older adults with concerns about declines in cognitive function and the ability to hear in noisy environments. The adaptability of computer technology allows for fine manipulation of training stimuli, such as consonant–vowel (CV) transition times in a speech signal, allowing users to progress from easy to challenging perceptual tasks. In a previous study, we used an auditory-based cognitive training program (described in Smith et al., 2009) that combined adaptively expanding CV transition times and memory demands to determine if training improves neural and behavioral speech-in-noise processing and cognitive functions of memory and speed of processing in older adults (ages 55–70) (Anderson, White-Schwoch, Parbery-Clark, & Kraus, 2013a). We evaluated neural speech-in-noise processing with the frequency following response (FFR) to a CV syllable presented in quiet and noise and found that training decreased FFR peak latencies and peak variability, two putative measures of subcortical neural synchrony, and improved untrained measures of sentence recognition in noise, short-term memory, and speed of processing. We used the FFR because it reflects temporal processing deficits in older adults (Anderson, Parbery-Clark, White-Schwoch, & Kraus, 2012; Clinard & Tremblay, 2013; Vander Werff & Burns, 2011) and because it can be modulated by training in young adults (Carcagno & Plack, 2011; Song, Skoe, Banai, & Kraus, 2012; Song, Skoe, Wong, & Kraus, 2008). The FFR reflects neural transcription of stimulus properties and is highly modulated by cognitive influences (Kraus & Chandrasekaran, 2010; Krishnan, Gandour, & Bidelman, 2010). In the current study, we investigated whether or not these effects of training on FFR processing and perceptual and cognitive function were maintained in older adults six months after cessation of training. In the following paragraphs,

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we outline training considerations for older adults and the evidence for generalization to untrained tasks and persistence of training benefits.

Effective training should target declines in sensory and cognitive processing and other domains that are known to decline with age. Reductions in speed of processing may underlie broad changes in cognitive function, including memory (Salthouse, 1996). In the auditory domain, these declines may contribute to the older adult's difficulties when trying to understand spoken communication, especially in challenging listening situations. Precise temporal resolution in the auditory system is required for the discrimination of speech stimuli (Phillips, Gordon-Salant, Fitzgibbons, & Yeni-Komshian, 2000), both in individuals with hearing loss and with audiometrically-normal hearing. Examples of age-related deficits in temporal resolution are seen in delayed midbrain and cortical peak latencies (Anderson et al., 2012; Clinard & Tremblay, 2013; Lister, Maxfield, Pitt, & Gonzalez, 2011; Tremblay, Piskosz, & Souza., 2003), delayed recovery in single neurons in inferior colliculus (Walton, Frisina, & O'Neill, 1998), loss of temporal coding by fusiform cells in dorsal cochlear nucleus (Wang et al., 2009), lower response amplitudes to amplitude-modulated tones (Parthasarathy & Bartlett, 2011), and reduced post-onset suppression in auditory cortex (Hughes, Turner, Parrish, & Caspary, 2010). Age-related declines in cognitive function can further exacerbate the effects of reduced temporal processing on speech perception, especially in unfavorable listening environments that may mask redundant speech cues (Pichora-Fuller, Schneider, & Daneman, 1995). These studies suggest that training that targets both perceptual and cognitive function is likely to be most effective for addressing age-related concerns.

Mahncke, Bronstone, and Merzenich (2006) have proposed that perceptual training can enhance cognitive performance. In fact, Berry et al. (2010) found that visual discrimination gains were associated with improvement on an untrained working memory task and that the change in N1 amplitude after training (an evoked cortical measure associated with attention; Coch, Sanders, & Neville, 2005) was highly correlated with the extent of working memory improvement. This link between perceptual training and cognitive performance is especially important, because reduced auditory input can impede cognitive function, particularly working memory (Pichora-Fuller, Schneider, & Daneman, 1995). Just as perceptual training is associated with cognitive gains, perhaps cognitive training can improve perceptual performance, especially in light of evidence that age-related declines in sensory function can be compensated by higher-level cognitive and attentional processes (reviewed in Grady, 2012; Li & Lindenberger, 2002; Wong et al., 2009). Wong and colleagues (2010) documented this cognitive compensation in older adults using fMRI to evaluate cortical processing of words in noise. They found reduced activity in auditory cortex but increased activity in prefrontal and precuneous regions – areas associated with memory and attention – in older vs. younger adults. Increased activity in cognitive regions was associated with better performance on a word recognition in noise task, but only in older adults, providing physiological evidence for the importance of memory and attention for hearing in noise in older adults. These results are in line with the Decline Compensation Hypothesis, which states that declines in sensory processing are accompanied by recruitment of general cognitive areas (Cabeza et al., 2004). Both the Berry and the Wong studies reinforce the idea that combining perceptual and cognitive training may engender lasting benefits for communication skills.

Another important consideration is generalization. For any program to be adopted and useful, the training must generalize from trained to untrained tasks or stimuli, especially those important for real world skills (as reviewed in Fahle, 2005). Previous evidence supports generalization for both perceptual and cognitive tasks in older adults. One study that addressed perceptual generalization showed that although older adults require more sessions to improve performance on a spectro-modulation detection task than younger adults, the generalization of their performance to untrained stimuli was actually better than the generalization in younger adults (Sabin et al., 2013). In a demonstration of transfer to off-task cognitive abilities, older adults who were trained using an auditory-based cognitive software program also had gains on an untrained memory test (Smith et al., 2009). Taken together, these studies demonstrate the potential for cognitive and perceptual training benefits to transfer to more general perceptual and cognitive skills in older adults.

The maintenance of training gains should also be considered when evaluating treatment efficacy, and there is evidence for the maintenance of cognitive gains in older adults. In older participants (i.e., 65–75 years), gains on untrained tasks involving fluid intelligence (e.g., pattern recognition) and speed of processing, but not working memory, were maintained for eight months (Borella, Carretti, Riboldi, & De Beni, 2010). In individuals of more advanced age (i.e., 75–86 years), however, performance on trained tasks was maintained for eight months but the generalization effects were less robust (Borella, Carretti, Zanoni, Zavagnin, & De Beni, 2013). Although no evidence as yet demonstrates the maintenance of perceptual gains in older adults, young adults maintain gains in sentence recognition in noise and enhanced subcortical encoding of a speech syllable in noise for up to six months after using a 20-day speech-in-noise training program (Song, Skoe, Banai, & Kraus, 2012). Given this limited information, there is clearly a need for further investigation into the long-term maintenance of training, especially in older adults. In this study, we investigated the potential maintenance of neural, perceptual, and cognitive training benefits after six months. Based on the Song et al. (2012) findings, we hypothesize that improvements in subcortical temporal processing (decreased latencies and inter-peak variability) and speech-in-noise performance persist for several months. We also hypothesize that gains in speed of processing, but not memory, are maintained after the cessation of training based on Borella et al. (2010).

2. Methods

2.1. Participants

We invited the 67 participants from our original training study to return for a six-month follow-up visit, and 62 participants (34 female) ranging in age from 55 to 70 years returned. We report statistics from the 62 participants who participated in all three sessions, and so there are slight differences in the means and statistical comparisons at post-test from those reported in Anderson, White-Schwoch, Parbery-Clark, and Kraus (2013b). No participants had a history of neurologic conditions, and all participants had normal IQs (≥ 85 on the WASI (Zhu & Garcia, 1999)).

Audiometric thresholds were measured at octave intervals from 0.125 to 8 kHz, including interoctave intervals at 3 and 6 kHz, plus 10 kHz and 12.5 kHz. No changes in threshold (≥ 10 dB) in any participant were noted from the previous sessions. Click-evoked auditory brainstem responses were obtained bilaterally (100 μs click presented at 80 dB SPL at 31.25 Hz), and no Wave V latency changes (≥ 0.05 ms) from the previous sessions were found in any participant.

All procedures were reviewed and approved by the Northwestern University Institutional Review Board. Participants provided informed consent and were compensated for their time.

2.2. Participant groups

In the original study, participants were randomly assigned to one of two treatment groups, *auditory training* or *active control* (towards the end of the study, targeted enrollment was done to ensure that the groups were matched on age, sex, hearing, and IQ). Both groups completed eight weeks of in-home auditory-based activities on home computers, one hour per day, five days per week, and both groups used headphones (Koss UR/29, Koss Corporation, Milwaukee, WI) to listen