A Randomized Control Trial: Supplementing Hearing Aid Use with Listening and Communication Enhancement (LACE) Auditory Training

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Objective: To examine the effectiveness of the Listening and Communication Enhancement (LACE) program as a supplement to standard-of-care hearing aid intervention in a Veteran population.

Design: A multisite randomized controlled trial was conducted to compare outcomes following standard-of-care hearing aid intervention supplemented with (1) LACE training using the 10-session DVD format, (2) LACE training using the 20-session computer-based format, (3) placebo auditory training (AT) consisting of actively listening to 10 hr of digitized books on a computer, and (4) educational counseling—the control group. The study involved 3 VA sites and enrolled 279 veterans. Both new and experienced hearing aid users participated to determine if outcomes differed as a function of hearing aid user status. Data for five behavioral and two self-report measures were collected during three research visits: baseline, immediately following the intervention period, and at 6 months postintervention. The five behavioral measures were selected to determine whether the perceptual and cognitive skills targeted in LACE training generalized to untrained tasks that required similar underlying skills. The two self-report measures were completed to determine whether the training resulted in a lessening of activity limitations and participation restrictions. Outcomes were obtained from 263 participants immediately following the intervention period and from 243 participants 6 months postintervention. Analyses of covariance comparing performance on each outcome measure separately were conducted using intervention and hearing aid user status as between-subject factors, visit as a within-subject factor, and baseline performance as a covariate.

Results: No statistically significant main effects or interactions were found for the use of LACE on any outcome measure.

Conclusions: Findings from this randomized controlled trial show that LACE training does not result in improved outcomes over standard-of-care hearing aid intervention alone. Potential benefits of AT may be different than those assessed by the performance and self-report measures utilized here. Individual differences not assessed in this study should be examined to evaluate whether AT with LACE has any benefits for particular individuals. Clinically, these findings suggest that audiologists may want to temper the expectations of their patients who embark on LACE training.

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INTRODUCTION

Despite significant advances in hearing aid technology, only about 14% of individuals >50 years old who might benefit from hearing aids use them (Chien & Lin 2012). Furthermore, there is wide individual variation in treatment outcome among those using amplification (Humes 2013). One approach to improving hearing aid outcomes is the provision of auditory training (AT), or systematic listening practice, aimed at maximizing the use of an individual's residual hearing. AT relies on the assumption that neurons in the brain can reorganize and restructure following, for example, training or changes in sensory input (Kraus et al. 1995; Ramachandran 2005; Reuter-Lorenz & Lustig 2005). The possibility that an adult with hearing loss could be "trained" or "retrained" to use bottom-up and top-down auditory processing skills is rooted in the recognition that (1) hearing aids cannot restore the auditory system to normal, (2) hearing aid processed signals differ acoustically from unprocessed signals, and (3) the auditory system of a patient acquiring hearing aids likely has been deprived of normal auditory input for several years.

Although there are data demonstrating that AT can result in improvements in the understanding of speech-in-noise (see Sweetow & Palmer 2005; Chisolm & Arnold 2012 for reviews), AT is not commonly recommended to adults with hearing loss. This may in part be due to limited reimbursement for adult audiologic rehabilitation as well as the concomitant time-, resource-, and cost-constraints associated with clinician-driven intervention models. One approach to addressing these limitations is the use of computer-based AT. A number of computer-based training programs exist, such as CasperSent (Boothroyd 2008), the Frequent-Word auditory training protocol (Humes et al. 2009), Listening and Communication Enhancement (LACE; Sweetow & Sabes 2006), and Speech Perception Assessment and Training System (Miller et al. 2007). Although these programs differ in the specific skills trained, they are similar in terms of the underlying training principles, which include adaptive algorithms that maintain training difficulty at a level near the upper limits of the user's auditory ability, the provision of feedback to promote learning, "rewards" to increase motivation, and the expectation that the user will train almost daily over several weeks. A fundamental assumption of any AT program is that the skills learned within the program will "generalize" or "transfer" to untrained stimuli and/or to everyday listening situations.

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In a recent systematic review, Henshaw and Ferguson (2013) synthesized the results of 13 studies investigating outcomes of computer-based AT for adults with hearing loss. Methodological limitations were identified in each of the studies reviewed, with only four being of at least moderate quality. The highest rated study was for the Sweetow and Sabes (2006) examination of LACE training, although even that study was judged to be of moderate quality, with robust improvements in performance consistently not observed. Henshaw and Ferguson concluded that the available evidence could not reliably guide the selection of a particular AT approach but that because computer-based AT provides a flexible, time- and cost–effective approach to hearing rehabilitation, there was a need for further efficacy studies.

The present investigation aimed to increase the evidence-base for computer-based AT for adults with hearing loss by further examining outcomes from using the LACE program described in Sweetow and Sabes (2006). LACE computer-based training consists of five tasks on which users are expected to train for a total of 30 min a day for 20 days over a 4-week period. Three of the LACE tasks train listening to degraded speech (speech-in-noise, rapid speech, competing speakers), and two tasks aim to improve cognitive processes related to auditory memory (word memory task) and the use of linguistic and contextual cues in the speech recognition process (missing word task). In addition, communication hints that provide recommendations about listening strategies and environmental modifications are interspersed between training tasks.

Initial evidence supporting the efficacy of LACE was provided by Sweetow and Sabes (2006) who studied 65 adult participants randomly assigned to either conduct 4 weeks of training immediately after baseline testing (immediate treatment group, n = 38), or to conduct training one month after baseline testing (delayed treatment group, n = 27). They reported statistically significant baseline-to-post training differences on the Quick Speech in Noise test (QuickSIN, Killion et al. 2004), on a test of auditory working memory (Pichora-Fuller et al. 1995), the Stroop Color Word test (Uttl & Graf 1997), the Hearing Handicap Inventory (HHI, Ventry & Weinstein 1982; Newman et al. 1990) and for the Communication Scale of Older Adults (Kaplan et al. 1997). There were no significant changes over the no-treatment period among the delayed-treatment group. These gains were maintained for at least 4 weeks postcompletion of training for 42 of the 65 participants. There are however methodological concerns with this study, including the lack of a power calculation to assure appropriate sample size and blinding of participants or examiners, a substantial drop-out rate (32% among the immediate treatment group), inclusion of normal-hearing participants, and the fact that the analyses only included within-group rather than between group comparisons.

Further support for the effectiveness of LACE training was reported by Song et al. (2012) who assessed perceptual and neurophysiological outcomes of 28 trained and 32 untrained participants with normal hearing. Small (~1 dB SNR) but statistically significant improvements on the QuickSIN and Hearing in Noise test (Nilsson et al. 1994) were shown for the trained group, both immediately after training and 6 months post training, but there were no significant changes in performance for the 32 control participants.

The only other published study to date that has examined LACE is by Olson et al. (2013). They trained 8 new and 14 experienced adult hearing aid users with a DVD version of LACE, and compared the outcomes to those of 7 new hearing aid users. There were no statistically significant effects of intervention for performance on a measure of speech-in-noise, time compressed speech or on self-reported hearing difficulties. There was, however, a significant benefit of training on the Synthetic Sentence Identification test with ipsilateral competing message (SSI; Speaks & Jerger 1965), and the new hearing aid users reported greater training benefits as measured using the International Outcome Inventory - Alternative Intervention (Noble 2002) than the experienced hearing aid users.

It is important to examine the effectiveness of potentially low-cost supplemental interventions aimed at improving hearing aid outcomes such as LACE with a population of Veterans with hearing loss because the Department of Veterans Affairs (VA) allocates substantial resources to meet the hearing healthcare needs of Veterans, and because data indicate that Veterans with hearing loss differ from private sector patients in their self-rated mental and physical health, reported participation restrictions, and hearing aid expectations (Cox et al. 2005). To this end, a multisite parallel group randomized controlled trial (RCT) was conducted at three VA sites comparing the DVD and computer-based versions of LACE with a placebo training condition and standard of care intervention. Outcome data were collected immediately following the intervention period and at 6 months postintervention. It was hypothesized that the outcomes obtained with both versions of LACE would be significantly better than the outcomes obtained with the placebo training and/or the standard of care intervention, both immediately following the intervention and six months later. No difference in outcome was expected between the two versions of LACE.

MATERIALS AND METHODS

This study is reported in accordance with the Consolidated Standards of Reporting Trials (CONSORT) 2010 guidelines for reporting parallel group randomized trials (Schulz et al. 2010), which has the objective of standardizing and improving the way RCTs are reported.

Participants

Two-hundred and seventy-nine Veterans were recruited from three sites: Bay Pines VA Healthcare System FL, Mountain Home VA Medical Center TN, and the Portland VA Medical Center OR between January 2009 and March 2011. The number of participants recruited for the study was based on a power analysis that assumed a 10% withdrawal rate (based on previous studies in our laboratories) and a Cohen's *d* detectable treatment effect of 0.31 for a speech-in-noise task as suggested by the results reported by Sweetow and Sabes (2006) with an alpha level set to 0.05 and a power to 0.80. The participants were recruited from the audiology clinic at each site, through Institutional Review Board-approved fliers posted around the local VA facility, and through letters sent to individuals who had recently attended an appointment at the audiology clinic (Portland).

All participants spoke English as their first language, and had age and educationally appropriate scores on the mini mental status examination (Folstein et al. 1975; Crum et al. 1993), had the ability to read at the 5th-grade level or higher as assessed with Woodcock Johnson III Letter-Word Identification, Reading Fluency, and Passage Comprehension subtests (Woodcock et al. 2001), and had best-corrected vision better

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than 20/63 as measured with the Smith Kettlewell Institute Low Luminance Card (Haegerstrom-Portnoy et al. 1997). None of the participants had signs of external ear disease, conductive or retro-cochlear pathology, an infectious disease, or comorbid illnesses that would interfere with their participation. The participants also were required to have a three frequency (500, 1000, and 2000 Hz) pure-tone average (PTA) ≤50 dB HL (American National Standards Institute 2004) and symmetrical hearing (left and right ear PTAs within 15 dB), and unaided speech recognition in quiet ≥40% assessed binaurally using List 4A of the Northwestern University Auditory Test No. 6 (NU-6; Tillman & Carhart 1966; Department of Veterans Affairs 2006) presented at 80 dB HL through earphones. In addition, the participants had to be willing to use hearing aids programmed so that the real-ear output with a 65 dB SPL input signal matched the National Acoustic Laboratories Non-Linear 1 (NAL-NL1) prescribed hearing aid output response target (Byrne et al. 2001) as described in "hearing aids" below.

Of the 279 participants, 136 (48.7%) were new hearing aid users (individuals who had worn hearing aids < 6 months in their lifetime but for a minimum of 4 weeks to allow for potential acclimatization) and 143 (51.3%) were experienced users (individuals who had used hearing aids for ≥6 months, but to ensure that they were using recent technology their current hearing aids had to be still in production by hearing aid manufacturers at the time of recruitment, with participants having used them for at least 4 weeks before study enrollment). Table 1 provides group mean data for age, better ear PTA, better ear four-frequency PTA (mean 500, 1000, 2000, and 4000 Hz), and binaural word (NU-6) recognition in quiet, by hearing aid user status and intervention group. Also included in Table 1 are unaided binaural word recognition in noise performances assessed using the Words-in-Noise test (WIN; Wilson 2003; Wilson et al. 2003; Wilson & McArdle 2007). The WIN is described in detail below. The mean data for the five measures included in Table 1 are almost identical across the four intervention groups and the two hearing aid user groups. Indeed, analyses of variance revealed no significant main effects or interactions on any of these variables, indicating equivalence among individuals in the four intervention groups and in the two hearing aid users groups. Furthermore, χ^2 analyses revealed no significant differences in the distribution of ethnicity and education among the intervention groups and/or as a function of hearing aid user status. Table 1 in Supplemental Digital Content (http://links.lww.com/EANDH/A259) provides complete audiometric data by frequency, ear, hearing aid user status, and intervention group.

Hearing Aids • The hearing aids used were on the National VA Hearing Aid Contract and had advanced digital technology features, such as multiple channels with independent compression characteristics, automatic noise reduction, active feedback cancellation, and directional microphones. The majority of the hearing aids were from one major manufacturer, but other major manufacturers also were represented. The hearing aids were fitted as a part of routine clinical practice. Their functionality was monitored throughout the study by measurement of electroacoustic performance (American National Standards Institute 2003) to ensure the instruments were within ANSI S3.22-2003-specified acceptable tolerances, and through probe tube microphone measurement of real-ear output. The real-ear output criterion for the study required that a 65 dB SPL input signal matched the NAL-NL1 prescribed aided output response target within 5 and −8 dB from 250 to 3000 Hz, and within 10 and −13 dB at 4000 Hz (the additional 3 dB below target variance is to allow for the effects of binaural summation).

Interventions

There were four intervention groups (LACE-DVD, LACE-C, placebo, and control) as described below.

LACE-DVD: Auditory Training for 10 Sessions of About 30 Min Each • The LACE-DVD intervention group used the DVD version of the LACE program from Neurotone, Inc. (www.neurotone.com). The participants were loaned a standalone DVD player (Insignia, Model NS-PDVD10) and were instructed to complete 10 training sessions of 30 min each over a 2-week intervention period.

LACE-C: Auditory Training for 20 Sessions of About 30 Min Each • The LACE-C intervention group used the computer-based version of the LACE program of Sweetow and Sabes (2006) distributed by Neurotone, Inc. The participants were loaned a laptop computer (Dell Vostro 1000) with external loudspeakers (Meyer Sound Lark) and were instructed to complete 20 training sessions of 30 min each over a 4-week intervention period.

TABLE 1. Group mean demographic data with one standard deviation in parentheses

			Better Ear				
Group	Hearing Aid User Status	N	Age (Years)	PTA* (dB HL)	4F-PTA† (dB HL)	NU-6 (AU) % Correct	Unaided WIN 50% dB SNR
LACE-DVD	New	33	67.6 (7.4)	29.3 (8.7)	45.6 (10.2)	89.1 (11.5)	11.2 (3.3)
	Experienced	35	68.9 (8.1)	29.4 (8.9)	45.6 (9.5)	87.0 (10.9)	11.1 (3.7)
LACE-C	New	32	68.7 (8.1)	27.5 (8.6)	44.2 (9.6)	91.0 (9.8)	10.7 (3.0)
	Experienced	33	69.3 (7.7)	30.4 (9.1)	46.7 (9.9)	86.3 (14.1)	10.7 (3.6)
Placebo	New	32	66.7 (7.6)	28.7 (8.5)	46.3 (10.2)	90.1 (8.3)	11.0 (3.5)
	Experienced	41	67.4 (7.8)	28.9 (10.4)	45.9 (11.0)	88.4 (9.3)	11.0 (3.3)
Control	New	39	71.0 (7.5)	29.8 (9.2)	44.9 (10.3)	87.0 (12.2)	11.4 (3.4)
	Experienced	34	68.9 (6.9)	29.8 (9.2)	47.2 (11.6)	85.1 (11.7)	12.0 (3.7)
All	New	136	68.6 (7.8)	24.4 (8.8)	45.3 (10.0)	89.2 (19.7)	11.1 (3.3)
	Experienced	143	68.5 (7.6)	29.6 (9.4)	46.4 (10.5)	86.8 (11.4)	11.2 (3.6)

*Pure-tone average: mean of thresholds at 500, 1000, and 2000 Hz.
†Four frequency pure-tone average: mean of thresholds at 500, 1000, 2000, and 4000 Hz.
WIN, Word-In-Noise test.

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Placebo Training for 20 Sessions • The Placebo intervention group listened to books that had been digitized and stored on a laptop. The same model of laptop computer and loudspeakers used by the LACE-C group were loaned to the participant for the 4-week intervention period. The participant chose one of five books that included fiction, nonfiction, humor, and adventure stories. Each book was divided into 20 listening sessions, with each session lasting about 30 min. Within each session, the book was divided into three or four "sections." After each section, the participant was required to answer two or three questions about the section content. Responses to the questions were not recorded because they simply served to encourage the participants to listen actively to the story.

Participants in the LACE-DVD, LACE-C, and placebo training groups were instructed to use their hearing aids during training set to a comfortable listening level.

Control Intervention • The primary intervention for the control group participants was the use of hearing aids but to equate time spent with the study audiologist across intervention groups during visit 2 (see below) individuals in the control group received a one-on-one educational counseling session that lasted approximately 30 min. During this session, the participants were provided with an overview of how the ear works and the impacts hearing loss has on the auditory system, their audiogram was explained to them and was plotted along with the typical level and frequency of speech phonemes (speech banana audiogram) so they could understand how their pure-tone thresholds might affect speech understanding. Finally, the limitations of hearing aids were discussed. This educational information was intended to be benign insofar as it was not expected to influence outcomes.

Outcome Measures

Speech understanding in noise assessed using the WIN was selected as the primary outcome measure. It was chosen because difficulty understanding speech-in-noise is the most common problem reported by individuals with age-related hearing loss. Four additional behavioral and two self-report measures were selected as secondary outcome measures. The behavioral measures were selected to examine whether the perceptual and cognitive skills targeted in LACE training generalized to untrained tasks that required similar underlying skills. The two self-report measures were completed to determine whether the training resulted in a lessening of activity limitations and participation restrictions.

Speech Understanding in Noise • The WIN, which uses NU-6 words spoken by the VA female speaker, was used to assess word recognition in six-talker babble (Department of Veterans Affairs 2006). The WIN consists of two 35-word lists presented at 7 signal to noise ratios (SNR), ranging from 24 to 0 dB, in 4-dB decrements with 5 words presented at each SNR. The level of the babble was constant at 70 dB HL and the level of the words was varied. Each word was presented in the carrier phrase "Say the word _____." The participants were instructed to repeat the last word in the phrase and to guess if they were unsure. They were informed that the words would become more difficult to hear as the level of speech decreased. Testing was terminated when all words at one SNR were repeated incorrectly. The data from the two lists were combined and the 50% point calculated with the Spearman-Kärber equation (Finney 1952). Although Sweetow and Sabes (2006) used the QuickSIN as the outcome measure for speech understanding in noise, the WIN was selected for the present study because the materials were spoken by the same female speaker who spoke the stimuli for two of the other outcome measures described below (rapid speech and competing speech measures), and because the WIN produces results comparable the results produced by the QuickSIN (Wilson et al. 2007). The correlation (r) between the QuickSIN and WIN data in that study was 0.79 (Wilson Reference Note 1*). Although the WIN is a word test involving mostly bottom-up processing with minimal top-down processing, the QuickSIN, which is a sentence test, has limited contextual cues in the sentences thereby minimizing the contribution made by top-down processing.

Rapid Speech • The ability to understand rapid speech was assessed with the NU-6 words spoken by the VA female speaker that were compressed 45% (45% CR) and 65% (65% CR; Wilson et al. 1994; Department of Veterans Affairs 1998). The 50 words in each list were compressed using the discard-interval model to preserve the pitch and prosody of the utterance. At both compression conditions, 50 words were presented in quiet at 70 dB HL. The participants were instructed to repeat the last word in the carrier phrase, "Say the word _____" and to guess if they were not sure what was said. The test was scored as the percent of correct responses for each compression condition.

Competing Speaker • The ability to understand speech in the presence of a competing speaker was examined using a modified version of the NU-20 test (Olsen & Carhart 1967), referred to here as the Northwestern University Auditory Test No. 20 competing message test (NU20-CM). The NU20-CM paradigm involves the NU-6 words spoken by the VA female talker in the presence of competing sentences (modified Bell Telephone Sentences; Fletcher & Steinberg 1929) spoken by a male (Wilson et al. 1990; Department of Veterans Affairs 2006). The version of the NU20-CM used here was modified into a descending SNR presentation paradigm similar to the WIN, in which 5 words were presented at each of 9 SNRs from 24 to −8 dB in 4 dB decrements (Smith et al. 2008). Two lists of 45 unique words each were used with the level of the competing sentences fixed at 70 dB HL and the level of the words varied. The participants were asked to repeat the last word in the carrier phrase while ignoring what the competing male speaker said. Data from the two lists were combined and the 50% point was calculated with the Spearman-Kärber equation.

Word Memory • Auditory word memory was assessed using a modified, recorded version of the Digit Span (DS) subtest of the Wechsler Adult Intelligence Scale 3rd edition (WAIS-III; Wechsler 1997). The DS protocol has two conditions, DS-forward (digits repeated in the sequence they were presented), which primarily taps short-term auditory memory, and DS-backward (digits repeated in the reverse sequence they were presented), which measures the ability to manipulate verbal information while in temporary storage. In the original WAIS-III protocol, the DS test is administered using live-voice presentation in which the examiner says digits (1 to 9) in a sequence with a ~1-sec interdigit interval. For the present study, the DS stimuli were modified by replacing the bisyllabic *7* with the monosyllabic 10. The nine digits were recorded by female talker (Wilson et al. 2008) and compiled by concatenating the required digits with 1-sec interdigit intervals into a set-size sequence with a 500-msec 500-Hz tone

* Wilson RH email dated 4/2/15.

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1 sec after the last digit in a sequence that served to prompt the listener to respond. In DS-forward condition, the number of digits per sequence increases from two to nine, whereas in DS-backward condition, the number of digits per sequence increases from two to eight. There were two trials for each digit-sequence set size (e.g., two trials of a two-digit sequence, two trials of a three-digit sequence, etc.). If all digits were repeated in the correct order, then the trial was given a score of 1; if the response in any way was incorrect, then the trial was given a score of 0. If either of the trials for a given digit-sequence size was repeated correctly, then the testing continued to the next digit-sequence size. A total score is obtained by summing all points with the maximum being 16 for DS-forward and 14 for DS-backward.

Use of Linguistic Context • To assess the ability to use linguistic contextual information, lists 3 and 4 of the revised-speech perception in noise (R-SPIN; Bilger 1984) in a modified descending SNR presentation paradigm were used (multi-SNR R-SPIN; Wilson et al. 2012). Each list consisted of 25 low-predictability (LP) and 25 high-predictability (HP) sentences that were presented in multitalker babble at 10 SNRs ranging from 23 to −4 dB in 3 dB decrements with 5 sentences presented at each SNR. At each SNR, two LP and three HP or three LP and two HP words were presented, with the same five target words used in LP and HP sentences at each SNR when the two lists were combined for scoring. The level of the babble was fixed at 70 dB HL and the level of the speech was varied. The participants were instructed to repeat the last word in each sentence and were encouraged to guess if they were not sure what the word was. The test was terminated when all five words at a SNR were incorrect. The Spearman-Kärber equation was used to compute the LP and HP 50% points on the data from the two lists. The SNR difference (in dB) between the LP and HP 50% points provided the estimate of the use of linguistic context.

Activity Limitations and Participation Restrictions • The abbreviated profile of hearing aid performance (APHAP; Cox & Alexander 1995) was used to assess activity limitations and the HHI for the elderly or adults (Ventry & Weinstein 1982; Newman et al. 1990) was used to assess participation restrictions. The APHAP is a 24-item questionnaire that documents hearing difficulties in specified listening situations. The items are answered on a 7-point scale from "always" (or 99%) to "never" (or 1%) with higher scores indicating greater reported hearing difficulty. The APHAP global score that ranges from 1 to 99 was used for all analyses. The HHI is a 25-item questionnaire that assesses the social and emotional consequences of hearing loss. The HHI for the elderly is for individuals age 65 years and older (Ventry & Weinstein 1982); the HHI for adults is for individuals aged 64 years and younger (Newman et al. 1990). The versions differ in the wording of three questions and typically, data from both versions are combined on the assumption that scores are equivalent. The participants were asked to complete the appropriate HHI for aided listening to reflect their residual hearing handicap. HHI items are answered on a scale of *Yes* (4 points), *Sometimes* (2 points), and *No* (0 points), with higher scores indicating greater reported hearing handicap. Total HHI scores, which can range from 0 to 100, were used for all analyses.

Randomization, Concealment of Allocation, and Blinding

Each site was provided with sequentially numbered randomization envelopes that specified the intervention group to which the participant was assigned. A block randomization scheme with a block size of eight was utilized with stratification of hearing aid experience (new or experienced listener) across the four intervention groups. Although it was not possible to mask (blind) participants in the control group from the fact that they were not receiving training, participants in the LACE-DVD, LACE-C, and placebo groups were masked regarding whether they were receiving experimental or placebo training. The research audiologists were not blinded to the participant's intervention-arm assignment.

Procedures

The participants attended four study visits and were compensated $25 for each visit. The study was approved by the Institutional Review Boards and the Research and Development Committees at each site.

Visit 1 (V1) • The participants first signed a consent form to confirm they understood the study purpose and procedures. Inclusion–exclusion assessments then were conducted in a fixed order: mini mental status examination, Smith Kettlewell Institute Low Luminance card, Woodcock-Johnson III Letter-word Identification, Reading Fluency and Passage Comprehension subtests, audiometric evaluation, and unaided binaural speech recognition in quiet. Individuals meeting all inclusion criteria were administered the WIN test unaided in the sound field, the materials for which were recorded on compact disc, fed through an audiometer (Grason-Stadler, Model 61) to a loudspeaker located at ear level, 1 m from the listener at a 0° azimuth. The participants' hearing aids were evaluated for functionality (electroacoustic analysis) and appropriateness (real-ear output match to NAL-NL1 prescriptive targets). If the hearing aids met the functionality and appropriateness requirements, then the participant was scheduled to return for baseline testing (visit 2). If the hearing aids did not meet the functionality requirements, then the hearing aids were sent to the manufacturer for repair. If the hearing aids did not meet the appropriateness requirements, then the aids were reprogrammed to meet the required output. Following reprogramming, participants wore their hearing aids for at least 4 weeks before attending visit 2. If an individual did not want to use the hearing aids at the reprogrammed settings, then the hearing aid settings were returned to their original settings and the individual did not participate in the study. V1 lasted 1.5 to 2.5 hr.

Visit 2 (V2, Baseline) • V2 took place within 6 weeks of V1. At the start of V2, hearing aid functionality was remeasured to confirm hearing aid function. The APHAP and the HHI then were administered in paper-and-pencil format, in a counterbalanced order such that even-numbered participants completed the APHAP before the HHI, and vice versa for odd-numbered participants. The study audiologist instructed the participants on questionnaire completion and was available to answer questions if needed. The five behavioral outcome measures were then administered in sound field, as described in V1 for the WIN unaided. For testing, the participants wore their hearing aids set to meet the NAL-NL1 target. If the hearing aids had no volume control, then this was the default output. If the hearing aids had a volume control, then the appropriate volume setting was determined through real-ear testing. The order in which the five behavioral tests were conducted was counterbalanced across participants. Once the baseline testing was complete,

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the participants received information about the intervention to which they had been randomized. Those in the LACE-DVD, LACE-C, or placebo groups were loaned the necessary equipment for conducting the training at home and were provided with a demonstration of how to set up the equipment as well as laminated diagrams and instructions for setting up and using the equipment at home. This took about 30 min. The participants in the control group received the educational counseling session, which also took about 30 min. V2 lasted 1.5 to 2.5 hr.

Intervention Period • The time between baseline testing (V2) and immediate postintervention testing (visit 3) was 2 to 6 weeks. During this period, the participants in the LACE-DVD, LACE-C, and placebo groups were instructed to complete the training to which they had been assigned and the participants in the control group were instructed to wear their hearing aids as usual. The study audiologist telephoned all participants 48 to 72 hr after V2. All were asked whether their hearing aids seemed to be functioning properly. In addition, the participants in the LACE-DVD, LACE-C, and placebo groups were asked whether they had successfully set up the study equipment and begun training. If a participant was having difficulties, then the study audiologist did her best to trouble-shoot over the telephone. If this was unsuccessful, then an additional visit to the research site was scheduled. The frequency with which problems occurred was not formally tracked, but equipment and set-up problems were rare. All participants were instructed to contact the study audiologist if they encountered problems with the equipment or with their hearing aids at any time during the intervention period.

Visit 3 (V3; Immediate Postintervention) and Visit 4 (V4; 6 Months Postintervention) • V3 occurred within 2 weeks of the end of the intervention period. V4 occurred 6 to 8 months following V3. All procedures during V3 and V4 were identical. First, hearing aid functionality was remeasured. The participants then completed the APHAP and HHI, and were administered the five behavioral outcome measures using the same procedures followed in V2. At V3, the APHAP and HHI were completed in the reverse order used during V2; at V4, the test order was the same order as during V2. For behavioral testing, the order of test administration was again counterbalanced across participants. V3 and V4 each lasted 1.0 to 1.5 hr.

Analytic Methods

The analyses were conducted to determine whether LACE training had positive impacts on hearing aid outcomes relative to placebo training and standard-of-care hearing aid intervention with educational counseling (control). The individual items on all test measures were entered into a database and double checked by two individuals. For the WIN, NU20-CM, and multi-SNR R-SPIN, formulae in the database computed the 50%-correct points (in dB S/N) from the raw data. Scores on each test measure were compared separately using repeated measures general linear model (GLM) analyses of covariance (ANCOVAs) in which baseline score (V2) was used as a covariate. For each measure, there were two between-subject factors (intervention group, hearing aid user status) and one within-subject factor (visit). Mauchley's test from each ANCOVA was examined to determine whether model assumptions were met. If assumptions were not met then the degrees of freedom were corrected using the Greenhouse-Geisser estimate. The significance level for each ANCOVA was set to $p < 0.01$ to control the possibility of type I errors. It was planned that significant main effects and interactions would be examined further by posthoc testing using Bonferroni or Dunnett corrections as appropriate. Bonferroni corrections are appropriate when the interest is in all pairwise comparisons, whereas Dunnett corrections are appropriate when the interest is in comparing other groups against only one group. As applied here, Bonferroni corrections would be used to conduct posthoc testing involving visit and user status, and Dunnett corrections would be used to conduct posthoc analyses involving intervention. This is because our interest is in comparing each treatment (LACE-C, LACE-DVD, and placebo) to the control group rather than in comparing the treatments to one another. Effect sizes for the ANCOVAs were computed as partial eta squared (η_p^2) values, which represent the degree of association between an effect (i.e., intervention group, hearing aid user status, visit, or their interactions) and the dependent variable. Statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS) Version 17.0.

As seen from the CONSORT participant flow diagram in Figure 1, complete data were available for 279 participants at V1 and V2 (baseline). Of the original 279 participants, 263 completed V3 (immediate postintervention) and 243 completed V4 (6 months postintervention) for an overall attrition rate of 12.9%, which was just slightly higher than the anticipated 10% attrition rate. Chi-square analysis revealed no significant differences as a function of intervention group or hearing aid user status indicating that these variables did not influence attrition. In healthcare outcomes research, it is convention that the data for all participants assigned to a treatment group are analyzed based on the principle of "intention to treat" (Overall et al. 1998; Peduzzi et al. 2002). Inclusion of all participants recognizes the fact that individuals may fail to complete a protocol for a variety of reasons including dissatisfaction with the intervention. In the present study, dissatisfaction may explain why 5 participants did not return for V3. Specifically, 4 LACE-DVD participants reported difficulty using the DVD player, and one LACE-C participant indicated that using the computer for training was too stressful. Other reasons for attrition are provided in Figure 1.

Since the percentage of missing data was minimal, hypothetical outcome scores were estimated through the use of the iterative single imputation using the expectation maximization approach in the SPSS missing values analysis module. In the expectation maximization approach, data are considered to be *missing at random*. When data are considered to be missing at random, an assumption is made that the cases with incomplete data differ from those with complete data but that the pattern of the missing data is predictable from other variables in the database rather than being due to the specific outcome variable on which the data are missing (Peduzzi et al. 2002). In estimating the missing data for each measure, the following variables were utilized: intervention group, hearing aid user status, site, age, education level, left and right ear PTAs, left and right ear root mean square-deviation from prescribed hearing aid response target, unaided binaural NU-6 in quiet scores, unaided WIN scores, and baseline performance on all outcome measures. Visual inspection of the distributions of original datasets and datasets with inclusion of calculated missing values confirmed that the shapes of the original distributions were maintained after imputation, which is an important criterion in determining that the missing data approach selected was appropriate.

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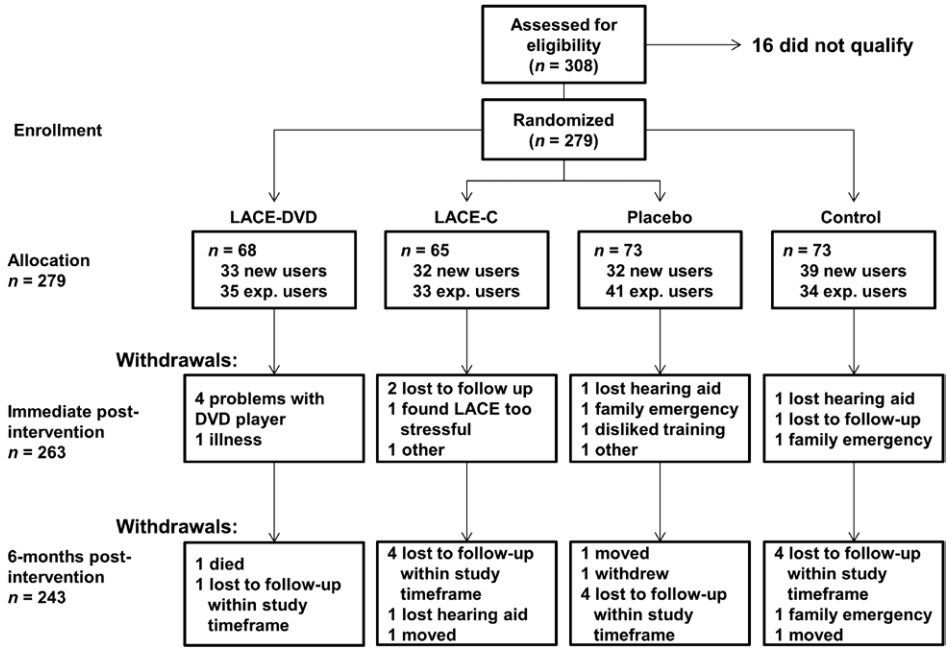

Fig. 1. Study participant flow.

RESULTS

Compliance with Interventions

Before reporting the main study findings, we report data regarding intervention compliance and sample representativeness because these are important considerations when interpreting data from a RCT. In order for an intervention to be effective, the patient needs to use the intervention. For this reason, the compliance with each intervention was examined. To assess compliance with LACE-DVD, it was necessary to rely on patient reports because the training data were not stored. Reported compliance (completion of all 10 training sessions) was about 85%. For the LACE-C participants, compliance data were available from the data uploaded to the LACE server on the Neurotone website. Of the 65 participants in the LACE-C group, data from 50 were uploaded. (The missing training data resulted from uploading limitations at VA facilities owing to cyber-security measures put in place during the course of the study and other technical difficulties.) For the 50 participants for whom compliance data were available, compliance was excellent: 84% of the participants (n = 42) completed all 20 training sessions, 6% (n = 3) completed 10 to 19 sessions, and 10% (n = 5) completed fewer than 10 sessions. Compliance of the placebo group also was not formally tracked; however, the program developed for the placebo condition permitted examination of the number of book sections to which each participant listened. This informal examination revealed approximately 80% of participants listened to all 20 sections of the books. Finally, it was assumed that all participants in each intervention group were compliant with using amplification based on informal discussions during each test visit. Further information about the compliance data for the present study is in Chisolm et al. (2013).

Intervention Outcomes

The results of GLM ANCOVAs on the imputed data by visit (V), the four intervention groups (I), and the two hearing aid user status groups (U) are presented in Table 2, and are discussed separately for each outcome measure below. Boxplots of the data for each visit by intervention group and users status are plotted for each outcome measure and can be found in Figures 2 to 6. Descriptive statistics for each measure by intervention and hearing aid user group are available in Tables 2 or 8 of Supplementary Digital Content (http://links.lww.com/EANDH/A259).

Speech Understanding in Noise • The WIN test was used to examine whether the LACE speech-in-noise training task generalized to different speech-in-noise materials. Figure 2 shows boxplots of WIN performance at each visit for intervention and hearing aid user status separately, with the means and standard deviations of WIN scores shown in Table 2 of Supplementary Digital Content (http://links.lww.com/EANDH/A259). The boxplots and Table 2 in Supplementary Digital Content (http://links.lww.com/EANDH/A259) show WIN performance to be very similar across visits, interventions, and hearing aid user status. The results from the GLM ANCOVA in Table 2 confirm that there were no significant main effects or interactions with intervention group (I), visit (V), or hearing aid user status (U), leading to the conclusion that there were not any benefits for understanding speech-in-noise demonstrated by the participants who conducted LACE AT compared with those who received the placebo training or the control intervention.

Rapid Speech • To assess the outcomes of training with the LACE rapid speech task, word recognition was examined with NU-6 word lists in two compression conditions (45% CR and 65% CR). The boxplots in Figure 3 and confirmed with the GLM ANCOVAs (Table 2) showed that there were no significant main effects or interactions with intervention group (I), visit (V), or hearing aid user status (U).

Competing Speaker • The NU20-CM, a modified version of the NU20 test, was used to examine the impact of the LACE competing speaker training. Again, as illustrated by the boxplot in Figure 4, and confirmed with the GLM ANCOVA in Table

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TABLE 2. Results of GLM analyses of covariance for each of the outcome measures using intervention group and hearing aid user status as between-subject factors, visit as a within-subject factor, and baseline score as a covariate

Outcome Measure	Source	df	*F*	*p*	η_p^2
WIN	Visit (V)	1,270	4.95	0.046	0.02
	Intervention (I)	3,270	0.14	0.935	0.01
	User status (U)	1,270	0.01	0.957	0.01
	V*I	3,270	0.33	0.804	0.01
	V*U	1,270	0.48	0.491	0.01
	I*U	3,270	0.50	0.682	0.01
	V*I*U	3,270	1.18	0.320	0.01
TCST 45% CR	Visit (V)	1,270	2.87	0.092	0.01
	Intervention (I)	3,270	0.60	0.615	0.01
	User status (U)	1,270	0.15	0.704	0.01
	V*I	3,270	1.65	0.178	0.02
	V*U	1,270	0.15	0.698	0.01
	I*U	3,270	1.84	0.140	0.02
	V*I*U	3,270	0.25	0.864	0.01
TCST 65% CR	Visit (V)	1,270	0.24	0.626	0.01
	Intervention (I)	3,270	2.72	0.045	0.03
	User status (U)	1,270	0.07	0.797	0.01
	V*I	3,270	1.61	0.189	0.02
	V*U	1,270	0.11	0.746	0.01
	I*U	3,270	0.52	0.670	0.01
	V*I*U	3,270	0.38	0.767	0.01
NU20-CM	Visit (V)	1,270	3.94	0.048	0.10
	Intervention (I)	3,270	0.55	0.649	0.01
	User status (U)	1,270	0.80	0.373	0.01
	V*I	3,270	1.28	0.281	0.01
	V*U	1,270	1.20	0.274	0.01
	I*U	3,270	0.58	0.627	0.01
	V*I*U	3,270	1.91	0.128	0.02
DS-forward	Visit (V)	1,270	0.01	0.911	0.01
	Intervention (I)	3,270	0.86	0.465	0.01
	User status (U)	1,270	1.37	0.243	0.01
	V*I	3,270	0.72	0.538	0.01
	V*U	1,270	6.14	0.014	0.02
	I*U	3,270	0.19	0.904	0.01
	V*I*U	3,270	2.22	0.086	0.02
DS-backward	Visit (V)	1,270	0.41	0.523	0.01
	Intervention (I)	3,270	0.37	0.777	0.01
	User status (U)	1,270	0.19	0.668	0.01
	V*I	3,270	0.57	0.636	0.01
	V*U	1,270	5.34	0.022	0.02
	I*U	3,270	0.30	0.823	0.01
	V*I*U	3,270	1.94	0.124	0.02
Multi-SNR R-SPIN Linguistic Context use	Visit (V)	1,270	0.86	0.355	0.01
	Intervention (I)	3,270	1.36	0.255	0.02
	User status (U)	1,270	1.40	0.238	0.01
	V*I	3,270	0.30	0.822	0.01
	V*U	1,270	0.26	0.613	0.01
	I*U	3,270	1.03	0.380	0.01
	V*I*U	3,270	0.84	0.474	0.01
APHAP	Visit (V)	1,270	0.65	0.419	0.01
	Intervention (I)	3,270	0.13	0.940	0.01
	User status (U)	1,270	1.61	0.206	0.01
	V*I	3,270	0.05	0.985	0.01
	V*U	1,270	2.67	0.104	0.01
	I*U	3,270	0.61	0.612	0.00
	V*I*U	3,270	1.12	0.343	0.01
HHI	Visit (V)	1,270	0.58	0.448	0.01
	Intervention (I)	3,270	1.33	0.264	0.02
	User status (U)	1,270	2.80	0.095	0.01
	V*I	3,270	1.77	0.153	0.01
	V*U	1,270	1.63	0.203	0.01
	I*U	3,270	0.64	0.592	0.01
	V*I*U	3,270	1.98	0.117	0.02

To limit the possibility of type I errors the significance level is $p < 0.01$.

APHAP, abbreviated profile of hearing aid performance; DS-backward, digit span-backward; DS-forward, digit span-forward; HHI, hearing handicap inventory; Multi-SNR R-SPIN linguistic context use, multiple SNR revised-speech perception in noise; NU20-CM, Northwestern University Auditory Test No. 20 competing message test; TCST 45% CR, Time Compressed Speech test 45% compression ratio; TCST 65% CR, Time Compressed Speech test 65% compression ratio; WIN, Word-in-Noise test.

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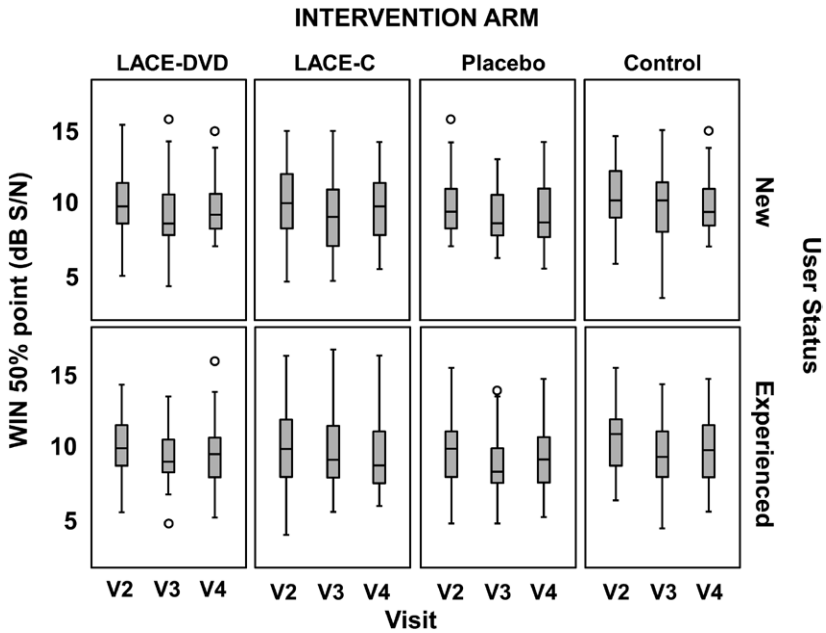

Fig. 2. Boxplot for WIN scores by visit for each intervention user group separately. The median value is shown by the *solid horizontal line* with the lower and upper ends of the box showing the 25th and 75th percentiles, respectively, and the upper and lower ends of the whisker indicating the range of values within 1.5 times the interquartile range. *Circles* depict outliers that are >2 whisker lengths above or below the 75th or 25th percentiles, respectively. WIN indicates Words-in-Noise test.

2, there were no statistically significant main effects or interactions involving visit, intervention, or user status.

Word Memory • The effectiveness of the LACE word memory training task was assessed using a recorded version of the DS task. As with the other measures presented so far, the boxplots in Figure 5 (DS-forward) and Figure 5 (DS-backward) and ANCOVAs showed there were no significant main effects or interactions involving intervention, visit, or user status.

Use of Linguistic Context • The LP minus HP performance on the multi-SNR R-SPIN materials was used to assess the impact of LACE training on use of linguistic context. The GLM ANCOVA for the use of linguistic context (Table 2) showed no statistically significant main effects or interactions involving intervention, visit, or hearing aid user status (see also Fig. 4).

Activity Limitations and Participation Restrictions • To determine whether training with LACE resulted in a decrease in perceived activity limitations or participation restrictions, the APHAP and HHI were completed. As with the behavioral measures, the GLM ANCOVAs, the boxplots in Figures 6) indicate no significant main effects or interactions with intervention, visit, or hearing aid user status for either the APHAP or the HHI data.

Relations Between Benefit and Baseline (V2) Performance

Based on previous research (Burk et al. 2006; Sabes & Sweetow 2007; Humes et al. 2009; Song et al. 2012; Ferguson et al. 2014), it was expected that baseline performance would be significantly correlated with postintervention performance, and thus we chose to use baseline performance as a covariate. Our assumption was confirmed through the use of Pearson correlations examining the relations between baseline performance and outcome. For many measures, the correlations in Table 3 indeed show lower baseline performance to be associated with greater benefit at V3 and V4. However, there were as many significant correlations between performance at V2 and benefit in performance at V3 and V4 among the placebo and control groups (Table 3, columns 3, 4, 7, and 8) as there were among the LACE-DVD and LACE-C groups (columns 1, 2, 5, and 6).

In summary, there were no statistically significant or clinically meaningful main effects or interactions between intervention and outcome for either hearing aid user group or for all participants combined on any of the outcomes assessed.

DISCUSSION

The purpose of this study was to determine whether supplementing hearing aid use with LACE training improved hearing rehabilitation outcomes in a Veteran population relative to placebo training or standard-of-care intervention. Overall, there was no evidence supporting improved outcomes from LACE training for either training format (computer or DVD). Olson et al. (2013) reported similar null results, whereas Sweetow and Sabes (2006) and Song et al. (2012) found more positive outcomes.

There are a number of possible explanations for these divergent findings. First, the participants in the present study and in the study of Olson et al. (2013) were all over age 50 years old (present study: mean = 68.6 years; range: 55 to 85 years.; Olson et al. mean = 66 years, range 52 to 81 years), whereas there were younger participants in the other studies (Sweetow & Sabes 2006: mean = 63.7 years, range = 28 to 85 years; Song et al. 2012, mean = 24.7 years, range = 19 to 35 years). Recent study has shown that differential perceptual learning takes place among individuals of different ages with similar hearing sensitivity (Wright et al. 2013; Huyck & Wright 2013; Sabin et al. 2013). Although the training tasks and algorithms in these studies were very different from LACE, the study suggests that differences

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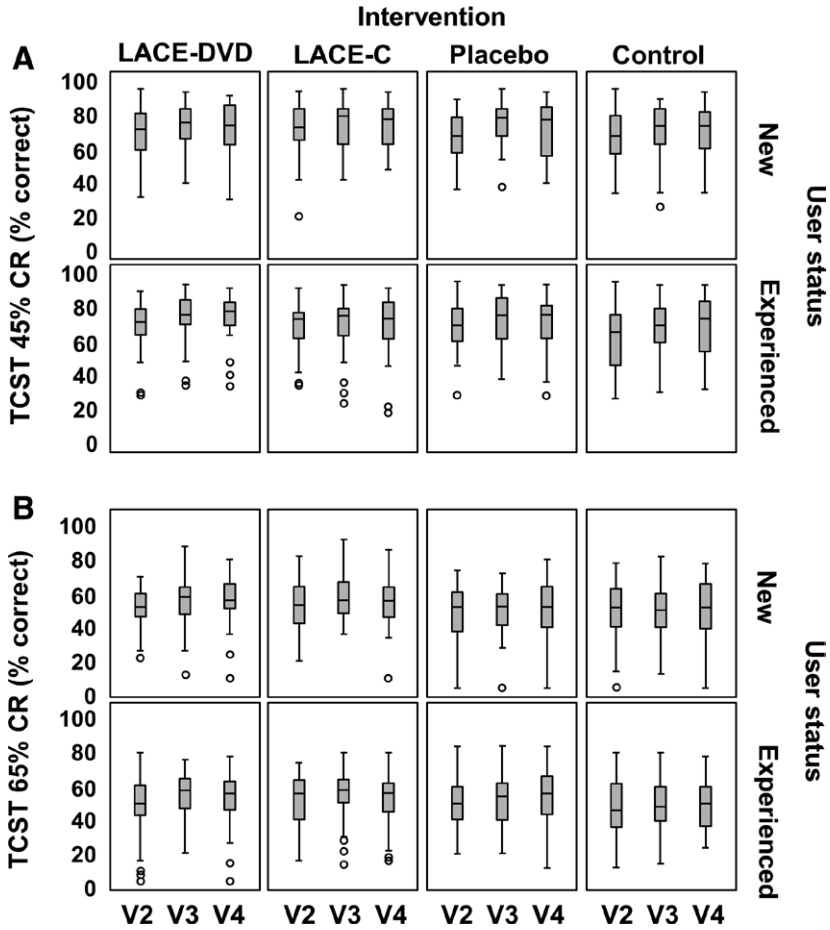

Fig. 3. Box plots for TCST 45% CR and TCST 65% CR, respectively, by visit for each intervention user group separately. The median value is shown by the *solid horizontal line* with the lower and upper ends of the box showing the 25th and 75th percentiles, respectively, and the upper and lower ends of the whisker indicating the range of values within 1.5 times the interquartile range. *Circles* depict outliers that are >2 whisker lengths above or below the 75th or 25th percentiles, respectively. TCST indicates Time Compressed Speech test.

in perceptual learning with age may be an explanation for our findings and those of others. Furthermore, duration of hearing loss, which is positively correlated with age, could have impacted the effectiveness of training as it does with outcomes following cochlear implantation (Blamey et al. 2013; Holden et al. 2013). Although a difficult study to design, research should be conducted to determine whether duration of hearing loss does indeed impact outcome following AT and, if so, whether extended training could overcome this effect and yield better outcomes.

Second, also related to the study populations, there were differences in degree of hearing impairment and in use of amplification across studies. Like the participants in this study, those of Olson et al. (2013) had mild to moderate sensorineural hearing loss (better ear 4F PTA = 41.3 dB HL; range: 20 to 67.5 dB HL), and almost half were new hearing aid users (<6 months use) with the remainder being experienced hearing aid users (≥6 months use). The participants of Sweetow and Sabes (2006) had PTAs that were on average poorer than those here but with a greater range (mean PTA = 38.4 dB HL, range = 1.7 to 102.0 dB HL). Furthermore, 14% of Sweetow and Sabes participants did not use amplification, and of those that did, all had used it for at least 6 months. In even greater contrast to the participants here, the participants of Song et al. (2012) all had normal hearing thresholds (≤ 20 dB HL from 125 to 8000 Hz), and therefore none used amplification. Although the underlying basis of a relation between degree of impairment, use of amplification, and training outcomes is not understood, this may explain the difference in outcomes.

Another important difference between the studies that have examined LACE training is the off-task outcome measures utilized. Although in each study, measures were selected aimed to assess the generalization of trained skills, it is not known whether they indeed tapped into equivalent constructs. Furthermore, the measures used likely vary in their reliability and sensitivity to change. For example, Sweetow and Sabes (2006) and Song et al. (2012) found small (~1.5 dB) but statistically significant differences between trained and untrained individuals on speech understanding in noise as measured using the QuickSIN, Olson et al. (2013) found just a marginal effect ($p<0.056$) of training using the same measure, and in the present study, no significant effects of intervention were found when the WIN was used to assess speech-in-noise performance. Effect sizes for these studies ranged from 0.23 (Sweetow & Sabes 2006), 0.32 (present study) to 1.50 (Olson et al. 2013). Song et al. did not present effect size data.

As mentioned earlier, the WIN (a word-based test) and the QuickSIN (a sentence-based test) produce recognition performances that are highly correlated. This is most likely because

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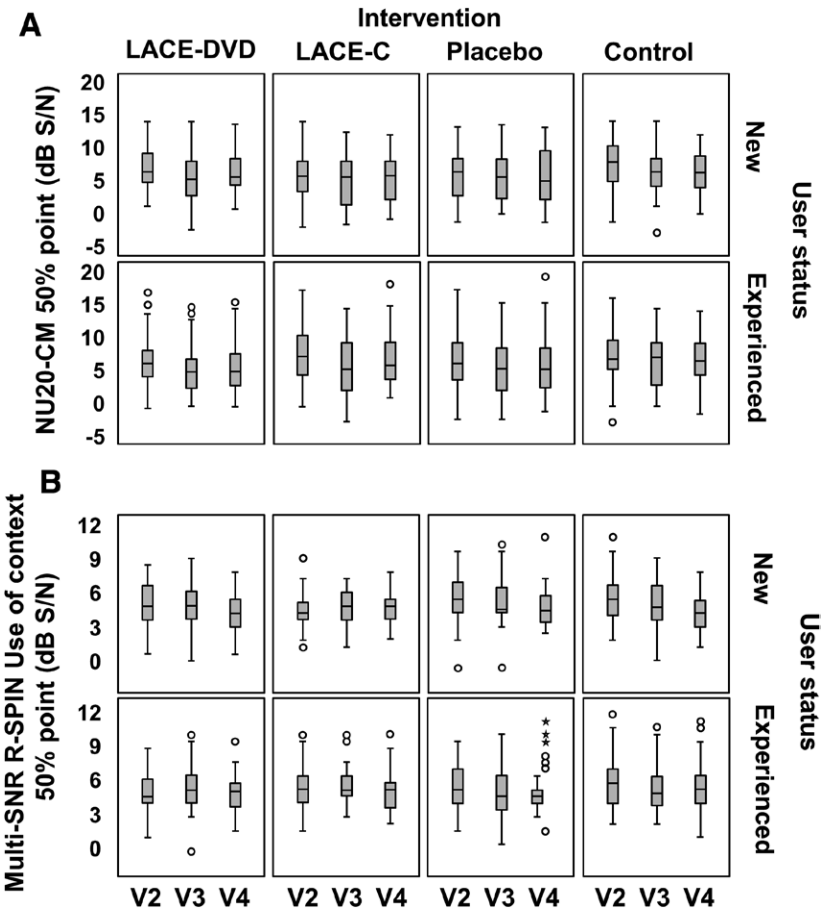

Fig. 4. Box plots for the NU20-CM and the multi-SNR R-SPIN use of context, respectively, by visit for each intervention user group separately. The median value is shown by the *solid horizontal line* with the lower and upper ends of the box showing the 25th and 75th percentiles, respectively, and the upper and lower ends of the whisker indicating the range of values within 1.5 times the interquartile range. *Circles* depict outliers that are >2 whisker lengths above or below the 75th or 25th percentiles, respectively, and the *asterisks* (B) depict outliers that are >3 whisker lengths above the 75th percentiles. Multi-SNR R-SPIN indicates multiple SNR revised-speech perception in noise; NU20-CM, Northwestern University Auditory Test No. 20 competing message test

QuickSIN sentences have limited contextual cues and thus little benefit from linguistic cues is obtained. Although this may explain the difference in findings between this study and that of Sweetow and Sabes (2006), note that Olson et al. (2013) also used the QuickSIN to assess speech understanding in noise and found just a marginal effect ($p < 0.056$) of training. Thus, whereas the use of a sentence-based measure of speech-in-noise may have permitted better examination of higher level linguistic processing skills, the data from the HP and LP conditions of the multi-SNR R-SPIN suggest otherwise.

Sweetow and Sabes (2006) also reported a significant effect of training on a sentence-based listening span measure assessing working memory that was conducted with a subset of 22 trained and 12 untrained participants. On average the trained participants improved by 0.5 sentences relative to no change among the untrained subjects. It is possible that the more complex sentence-based listening span measure was more sensitive to changes in working memory following training than the DS test used in the present study or that with so few participants conducting the test, the finding is statistically spurious.

In addition, Sweetow and Sabes (2006) observed significant improvements in off-task speed of processing among the trained participants relative to the untrained participants as measured with the Stroop test. Speed of processing in the present study was measured using a time-compressed word test. These two measures differ considerably in their content and it seems likely that they are tapping into different constructs. Likewise, Olson et al. (2013) found a statistically significant benefit of competing speaker training on the SSI for new and experienced hearing aid users. The test used in the present study to assess the effect of competing speaker training was the NU20-CM. No effect of training was measured. It may be that the SSI is more sensitive to changes following competing speaker training than the NU20-CM, or that the SSI is more prone to learning effects because it is an identification task, hence the difference in findings between studies.

It is of note that the impact of training on assessed activity limitations and participation restrictions were assessed using the HHI in the present study and in that of Sweetow and Sabes (2006). While no statistically significant improvements in HHI scores were shown following training in the present investigation, Sweetow and Sabes found significant improvements in HHI score. The change in score, however, was just 7.5 points, which is well below that published critical difference of 19.2 points, and the Cohen's *d* effect size was small (0.40) suggesting the changes measured by Sweetow and Sabes likely had little real world impact for participants.

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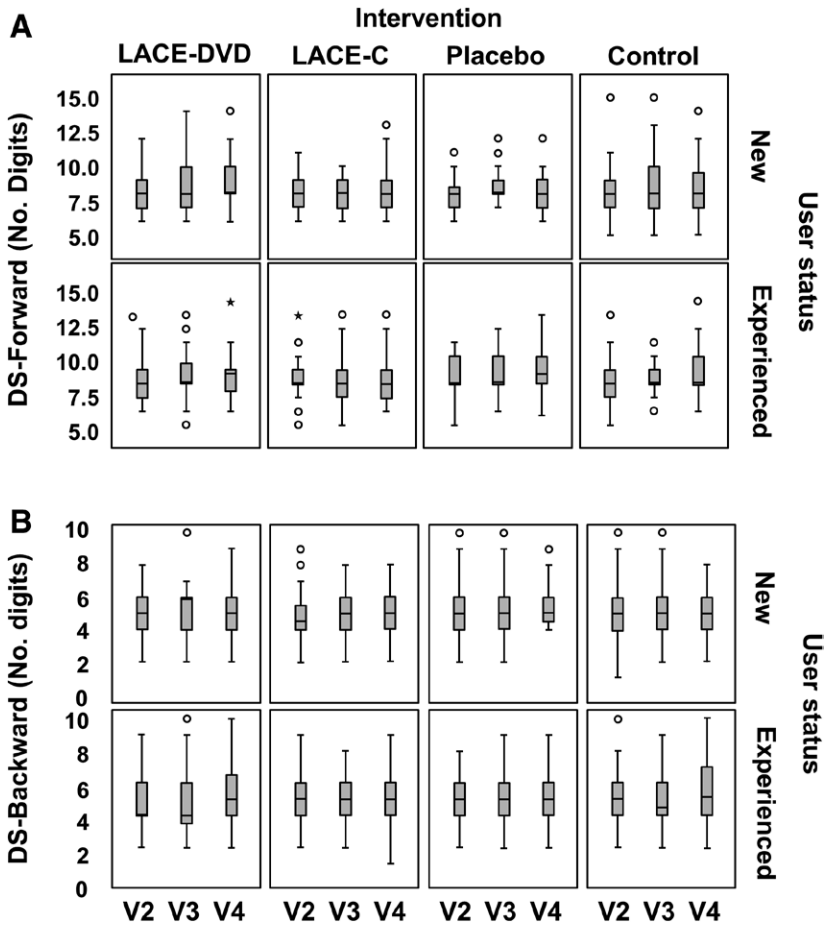

Fig. 5. Box plots for the DS-forward and DS-backward, respectively, by visit for each intervention user group separately. The median value is shown by the *solid horizontal line* with the lower and upper ends of the box showing the 25th and 75th percentiles, respectively, and the upper and lower ends of the whisker indicating the range of values within 1.5 times the interquartile range. *Circles* depict outliers that are >2 whisker lengths above or below the 75th or 25th percentiles, respectively, and the *asterisks* (A) depict outliers that are >3 whisker lengths above the 75th percentile. DS indicates digit span.

Perhaps the most important difference between the present study and that of other studies is design and analytical approach. Sweetow and Sabes (2006) used a design in which the participants were their own controls. The present study was a RCT in which between-group comparisons were made. When each patient serves as his or her own control, the effects of between-patient variation in outcome are diminished. There is little question that the outcomes in both studies were highly variable, which in the present RCT would have had a greater impact on statistical comparisons than the between-subject comparisons of Sweetow and Sabes. Although the heterogeneity typically observed among older listeners with hearing loss could argue for the use of crossover designs to assess interventions, the concern is that the data from each individual contributes a large proportion of the total information, thus dropout rates have a larger impact on the study outcome in within-group as compared with between-group trials (Velengtas et al. 2012). Indeed, Sweetow and Sabes and Olson et al. (2013) encountered substantial dropout rates of about 25 and 22%, respectively. Deceptively positive outcomes can occur if data from dropouts were not taken into account because those who drop out may have been the individuals who find a particular intervention unacceptable (Cox 2005). In the present study, not only was the drop-out rate low (12.9%) but we also confirmed that there was no interaction between drop-out rate and intervention, and the potential influence of drop-outs on outcome was addressed using statistical imputation in an intention-to-treat analysis as is recommended in clinical trials.

It is important to note that the null findings in this study relative to those of Sweetow and Sabes (2006) are not due to a lack of adherence to the training protocol. In fact, as described above and noted in Chisolm et al. (2013), not only was training adherence better in this study than in that of Sweetow and Sabes, and similar to that in Olson et al. (2013), the on-task training improvements of our participants were as great or greater than those of Sweetow and Sabes' participants (on-task training improvements were not reported by Olson et al.). Specifically, when comparing on-task performance after 5 training sessions and after 20 training sessions it is seen that LACE-C participants (the only intervention group for whom it was possible to track on-task training improvements) had improved by 1.9 dB SNR on the speech understanding in noise training task, by 8.7% compression on the rapid speech training task, by 3.1 dB SNR on the competing speaker training task by 0.7 "levels" on the word memory training task, and by 6.8 "lace units" on the use of linguistic content task (Chisolm et al. 2013). Although some of these metrics are difficult to

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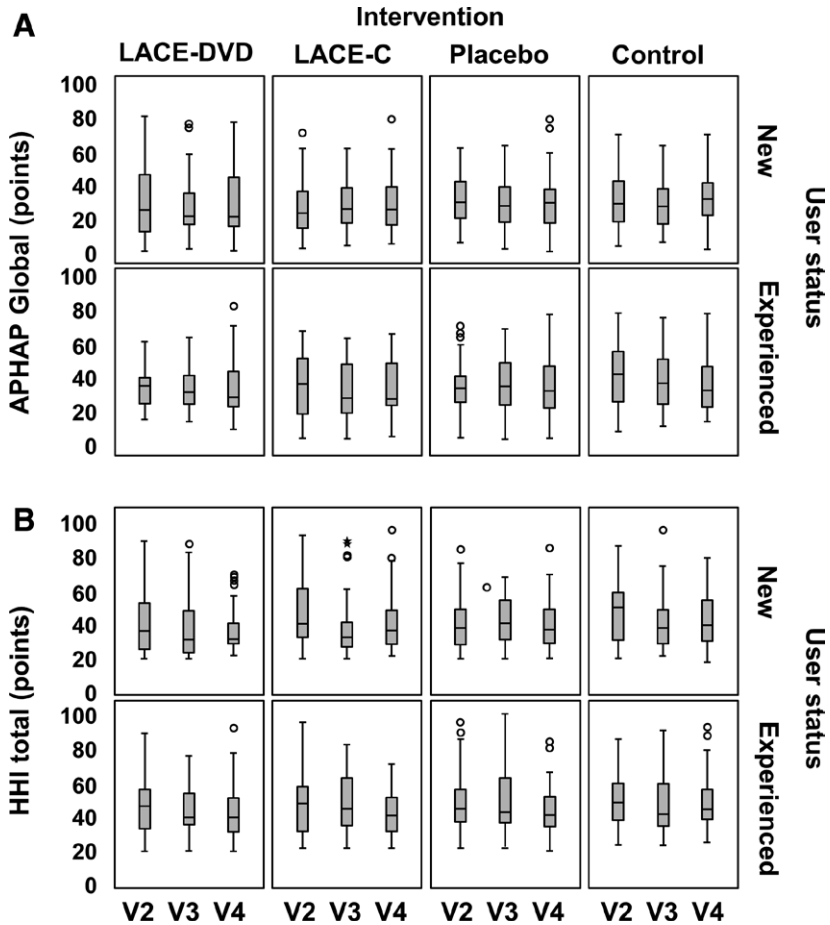

Fig. 6. Box plots for the APHAP global score and HHI total score, respectively, by visit for each intervention user group separately. The median value is shown by the *solid horizontal line* with the lower and upper ends of the box showing the 25th and 75th percentiles, respectively, and the upper and lower ends of the whisker indicating the range of values within 1.5 times the interquartile range. *Circles* depict outliers that are >2 whisker lengths above or below the 75th or 25th percentiles, respectively, and the asterisk (B) depicts an outlier that is >3 whisker lengths above the 75th percentile. APHAP indicates abbreviated profile of hearing aid performance; HHI, HHI, hearing handicap inventory.

interpret because they are specific to the LACE program, they each show an improvement in on-task performance over time.

The absence of robust generalization of trained skills following AT is typical of other studies. For example, Burk et al. (2006) reported improved scores on trained stimuli over time and some transfer of skills to untrained words, but they did not see generalization to trained words embedded in sentences or to untrained words in sentences. Likewise, Stecker

TABLE 3. Pearson correlations between performance at V2 and performance at V3 and V4 for each intervention arm separately

	V2 with V3				V2 with V4			
	LACE-DVD	LACE-C	Placebo	Control	LACE-DVD	LACE-C	Placebo	Control
WIN	0.16	0.36	0.49*	0.43*	0.27	0.50*	0.41*	0.57*
TCST 45% CR	–0.39	–0.22	–0.29	–0.47*	0.22	–0.25	–0.15	–0.39*
TCST 65% CR	–0.44*	–0.37	–0.28	–0.49*	–0.39	–0.38	–0.18	–0.40*
NU20-CM	0.29	0.32	0.33	0.43*	0.36	0.39	0.18	0.46*
DS-forward	–0.11	–0.36	–0.39	–0.34	–0.19	–0.32	–0.34	–0.27
DS-backward	–0.19	–0.58*	–0.47*	–0.44*	–0.28	–0.56*	–0.58*	–0.40
Linguistic context	–0.57*	–0.57*	–0.61*	–0.48	–0.55	–0.64	–0.56	–0.60
APHAP	0.38	0.34	0.36	0.47*	0.27	0.50*	0.32	0.57*
HHI	0.48*	0.51*	0.34	0.35	0.49*	0.46*	0.53*	0.30

To adjust for multiple analyses only correlations with an associated $p < 0.001$ were considered to be statistically significant.
**Correlation is significant at $p < 0.001$.*
APHAP, abbreviated profile of hearing aid performance; DS-backward, digit span-backward; DS-forward, digit span-forward; HHI, hearing handicap inventory; Linguistic context, multiple SNR revised-speech perception in noise; NU20-CM, Northwestern University Auditory Test No. 20 competing message test; TCST 45% CR, Time Compressed Speech test 45% compression ratio; TCST 65% CR, Time Compressed Speech test 65% compression ratio; WIN, Word-in-Noise test.

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et al. (2006) and Burk and Humes (2008) showed training generalized to untrained talkers but not to untrained stimuli, and Ferguson et al. (2014) showed no consistent improvements on untrained speech-in-noise measures. On the other hand, Humes et al. (2009) found that training of frequently occurring words resulted in greater transfer to open-set sentence recognition than their previous word-based training.

As with other studies (Burk et al. 2006; Sabes & Sweetow 2007; Humes et al. 2009; Song et al. 2012), the present study exhibited a negative relation between baseline performance and outcome, regardless of intervention group. That is, individuals with poorer performance at baseline showed the greatest improvement in score postintervention regardless of the intervention they received. This result suggests that many changes in performance might be associated with learning/practice effects rather than effects of the interventions themselves. The findings of Sabin et al. (2013) are relevant to this interpretation. Sabin et al. showed that a group of control listeners who did not train on a spectral modulation detection task showed as much improvement on the task as did a group of individuals who trained on the task for 1 hr each day over a 7-day period. Also relevant are the findings reported by Amitay et al. (2006) who found that individuals who trained on a visuospatial task subsequently improved on an untrained auditory frequency discrimination task. This improvement was seen in individuals who were exposed passively to the auditory signals while conducting the visuospatial training and in a group who were not. Improvement on the frequency discrimination task also was seen among individuals who were trained to discriminate between identical stimuli. The researchers concluded that merely engaging in a task can lead to improvements in performance on that task. It is likely that this phenomenon also was present in the present study.

Based on effect size but not statistical significance, Olson et al. (2013) reported that new hearing aid users showed greater benefit from LACE than experienced hearing aid users. This finding was not replicated in the present study. Although the definition of a new hearing aid user was the same in both studies (less than 6 months since a hearing aid was obtained), Olson et al. required experienced users to have had hearing aids for 2 years, whereas the present study required participants to have hearing aids for just 1 year. It is possible that both studies would have shown a greater effect of user status had hearing aid use been defined as a continuous variable such as months of ownership or based on actual hearing aid use as determined through data logging. Neither of these variables, however, is available for analysis.

Recent studies indicate that AT might have greater impacts on complex higher level executive skills, such as memory updating and task switching, than on lower level perceptual skills, such as understanding of words-in-noise (such as the WIN used here). For example, Ferguson et al. (2014) found that nonhearing aid users with hearing impaired individuals improved following AT on challenging measures of divided attention (the test of everyday attention – TEA dual-task decrement condition, Robertson et al. 1994) and working memory (visual letter monitoring, Gatehouse et al. 2003) but not on less complex measures such as a sentences-in-noise task (adaptive sentence list, McLeod & Summerfield 1990), the DS test or the TEA single attention task. Likewise, Kuchinsky et al. (2014) reported that 14 older adults with hearing loss who conducted AT improved over the untrained individuals on a test of word recognition in noise, reaction time, and showed changes in pupillary responses that were indicative of change in cognitive demand, and Anderson et al. (2013) showed improved scores on tests of short-term memory and attention among individuals who had conducted AT that were not seen in untrained individuals. There is little evidence to support this here beyond the finding of a marginally significant effect of intervention on the cognitively more complex measure used here (TCST 65% CR). Examination of Table 3 in Supplementary Digital Content (http://links.lww.com/EANDH/A259) shows that participants in the LACE-DVD and LACE-C groups had slightly better performance on this measure at V3 and V4 on the TCST 65% CR than did participants in the placebo and control groups. Note, similar to Ferguson et al., this pattern was not seen for DS-forward versus DS-backward measures. Thus, there remains the possibility that had the study focused on the use of outcome measures that assessed more complex cognitive function, the impacts of AT may have been more obvious.

CONCLUSION

Based on the analyses of group data from this RCT, the overarching conclusion is that LACE training does not result in improved outcomes over standard-of-care hearing aid intervention alone. Potential benefits of AT may be different than those assessed by the performance and self-report measures utilized here. Individual differences not assessed in this study should be examined to evaluate whether AT with LACE has any benefits for particular individuals. Variables of particular importance to assess might be motivation to train, opinions about the training program, and subjective perception of training benefits. Clinically, these findings suggest that audiologists may want to temper the expectations of their patients who embark on LACE training.

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