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Assessing the benefits of auditory training to real-world listening: identifying appropriate and sensitive outcomes

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Auditory training is an intervention that aims to improve auditory performance and help alleviate the difficulties associated with hearing loss. To be an effective intervention, any task-specific learning needs to transfer to functional benefits in real-world listening. The present study aimed to identify optimal outcome measures to assess the benefits of auditory training for people with hearing loss. Thirty existing hearing-aid users with mild-moderate sensorineural hearing loss trained on a phoneme discrimination in noise task. Complex measures of listening and cognition were assessed pre- and post-training. Functional benefits to everyday listening were examined using a dual-task of listening and memory and an adaptive two-competing talker task. There was significant on-task learning for the trained task ($p < .001$), and significant transfer of learning to improvements in competing speech ($p < .05$) and dual-task performance ($p < .01$). For the dual-task, improvements were shown for a challenging listening condition (0 dB SNR), with no improvements where the task was either too easy (in quiet) or too difficult (-4 dB SNR). Findings suggest that for listening abilities, the development of complex cognitive skills may be more important than the refinement of sensory processing. Outcome measures should be sensitive to the functional benefits of auditory training and set at an appropriately challenging level.

INTRODUCTION

Accumulating evidence suggests that the challenges faced by older people with hearing loss cannot be explained by the audiogram alone (Kiessling *et al.*, 2003). Difficulties in hearing may be exacerbated by, or masquerade as, reductions in cognitive ability such as problems remembering or comprehending speech (Pichora-Fuller *et al.*, 1995).

Auditory training (AT) can be described as teaching the brain to listen through active engagement with sound (Henshaw and Ferguson, 2013). Typically, listeners learn to make perceptual distinctions between sounds (e.g., tones, phonemes, words) presented systematically. It is suggested that AT may lead to improvements in speech perception through the refinement of sensory processing (historically termed

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analytic training), or the development of top-down repair strategies (synthetic training). A randomised controlled trial (RCT) of 50-74 year-old adults (n = 44) with mild sensorineural hearing loss (SNHL) who did not have hearing aids (Ferguson *et al.*, in press) showed significant improvements in a trained phoneme discrimination in quiet task ($p < .001$). Generalised improvements were shown for self-reported listening (particularly for a complex listening situation, $p < .01$, Cohen's $d = .68$), and complex cognitive tasks that engaged executive function (divided attention $p \leq .001$, $d = .53$; working-memory updating $p < .01$, $d = .50$). No improvements were shown for simple cognitive tasks or perception of ASL sentences in modulated noise. These findings suggest that the development of complex cognition may be more important than the refinement of sensory processing to improve communication in everyday life.

The present study employed a short phoneme-discrimination-in-noise training task to identify appropriate outcomes that were sensitive to the functional benefits of AT for real-world listening in 30 adult hearing-aid (HA) users with mild-moderate SNHL, aged 50-74 years.

METHODS

Study design

A within-participant repeated measures design was used (Fig. 1). Participants attended two baseline outcome assessment sessions (T0 and T1) to help account for any procedural learning (test-retest) effects on outcome measure performance. This was followed by a 1-week no-contact control period and a second assessment session (T2). Participants then trained at home for one week before the final post-training assessment session (T3).

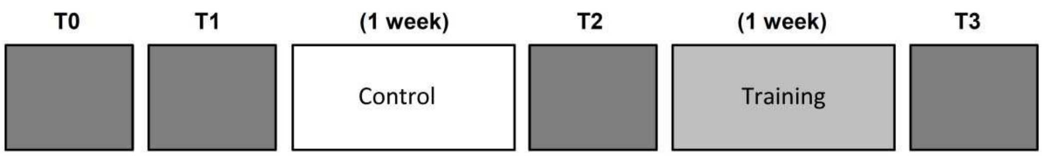

Fig. 1: Study design.

Participants

Thirty existing HA users (minimum HA experience = 3 months, mean = 10.3 years, SD = 10.7 years), aged 50-74 years (mean = 67.4 years, SD = 7.1 years) with mild or moderate SNHL (better-ear pure-tone thresholds averaged across 0.25, 0.5, 1, 2, and 4 kHz ranged between 21-69 dB HL, mean = 39.5 dB HL, SD = 12.7 dB), were recruited from the NIHR Nottingham Hearing Biomedical Research Unit research volunteer database.

Materials

Auditory training task: The phoneme-discrimination-in-noise task was delivered via computer game format (3I-3AFC oddball paradigm presented in ICRA multi-talker babble) using the IHR-STAR platform (for details, see Moore *et al.*, 2011). Participants trained using 11 different phoneme continua (/a/-/uh/, /b/-/d/, /d/-/g/, /e/-/a/, /er/-/or/, /i/-/e/, /l/-/r/, /m/-/n/, /s/-/sh/, /s/-/th/, and /v/-/w/). Each continuum transitioned from one phoneme to the other in 96 steps and was synthesised from end-points consisting of real voice recordings. Participants were presented with three discrete phonemes from one continuum per trial and were asked to identify the odd one out. Each phoneme continuum was presented for a block of 35 trials and the 11 continua were presented in sequential blocks on a rotational basis. A three-phase adaptive staircase procedure oddball response paradigm was used and threshold was the average of the last three trials in a block of 35 trials. Auditory and visual feedback (correct/incorrect response) was provided to participants after each trial. Participants completed two 15-minute training sessions each day, after which a graphical display showed the daily score for each continua plotted against their best score achieved. Visual rewards (on-screen fireworks) were shown when the participants improved on their previous best score.

Competing speech task: The Modified Coordinate Response Measure (MCRM) is a measure of speech intelligibility in the presence of a masker. The basic task, described by Hazan *et al.*, (2009), is based on the Coordinate Response Measure (Bolia *et al.*, 2000). For the present study, a single-talker masker was used. Participants were presented with sentences in the form of *'show the [animal] where the [colour] [number] is'*. There were six possible monosyllabic animals (cat, cow, dog, duck, pig, and sheep), six colours (black, blue, green, pink, red, and white) and eight numbers (1-9, excluding multisyllabic 7). Two sentences were presented concurrently, one by a female talker (target) and one by a male talker (distracter). Participants were asked to listen for the colour and number spoken by the female talker ('dog' was always the animal target) whilst ignoring the male talker, and to respond by pressing the corresponding target colour-number on a computer touchscreen. The test utilised an adaptive 1-up 1-down staircase method with an initial step size of 10 dB until reversal 1, reducing to 7 dB at reversal 2, and 4 dB at reversal 3 onwards. The test continued until eight reversals were achieved. Speech reception thresholds were calculated using the average of the last two reversals.

Letter-number sequencing task: A measure of working memory from the Wechsler Adult Intelligence Scale-Third Edition (WAIS-III; Wechsler, 1997) was used. Participants were presented with a string of pre-recorded spoken numbers and letters and were asked to repeat them aloud, with the numbers in numerical order followed by the letters in alphabetical order. Sequences began at two items, with three trials at each sequence length. If the participant responded correctly for one out of the three sequence trials then the sequence length was increased by one item (up to a maximum sequence length of eight items), otherwise the test was discontinued. The task was scored as the total number of sequence trials correct.

Dual-task of listening and memory: The dual-task measured listening and memory, and was designed to assess listening effort (Howard *et al.*, 2010). Participants completed a five-digit memory task (secondary task) that flanked a speech-in-noise repetition task (primary task). A string of five digits was displayed visually on a computer screen for five seconds. Participants were asked to retain the digits in memory for later recall. Participants were then presented with a list of five AB Isophonemic Monosyllabic Words (Boothroyd, 1968) and asked to repeat each word immediately after presentation. After each word list, participants were asked to recall the five previously presented digits. Word lists were presented in three noise conditions (quiet, 0 dB, or −4 dB SNR using ICRA multi-talker babble). There were 12 word lists (four per condition), and the presentation order for noise conditions was counter-balanced across participants. This resulted in a maximum possible score of 20 correctly-repeated words and 20 correctly-recalled digits for each noise condition.

Procedure

Auditory training: Instructions and two initial (five-trial) phoneme-discrimination-in-noise training demonstration tasks were completed by participants alongside the researcher in the laboratory prior to commencing at-home training. Participants were asked to complete the training at home for 30 minutes a day (2 × 15 minute sessions with a minimum break of 15 minutes) for seven consecutive days (requested training duration = 3.5 hours), which equates to just over half the training provided in the previous RCT (6 hours; Ferguson *et al*, in press). Training was delivered, and responses logged, using a laptop computer (Toshiba A300), which was locked-down to run only the auditory training program. Auditory stimuli were delivered through Logitech LS11 speakers with a maximum signal level of 75 dB(A) at 30 cm.

Outcome assessment: Outcome measures were obtained at each outcome assessment session in the lab. Speech perception and cognitive tests took place in a quiet, purpose-designed test room. Auditory elements were delivered via a Logitech LS11 speaker placed directly in front of the participant at a distance of 1 m.

RESULTS

On-task learning

Participants trained at-home for an average of 197.8 minutes (SD = 28.7 minutes). A linear mixed model was used to assess any main effects of time (block) or phoneme continua (task) on phoneme discrimination thresholds and any task*block interaction. There was a highly-significant main effect of block ($F(1,1419.51) = 32.67$, $p < .001$) and phoneme-discrimination thresholds improved over time (Fig. 2). There was also a highly-significant main effect of task ($F(10,1414.43) = 22.33$, $p < .001$). A second linear mixed model with data divided by task showed a significant improvement by block for the majority of phoneme continua at either the $p < .001$ (/a/-/uh/, /i./-/e/), $p < .01$ (/er/-/or/, /m/-/n/, /s/-/th/, /v/-/w/), or $p < .05$ level (/e/-/a/, /l/-/r/). There was no significant improvement over time for three of the four phoneme continua that had the poorest initial thresholds, /s/-/sh/ ($p = .051$), /b/-/d/

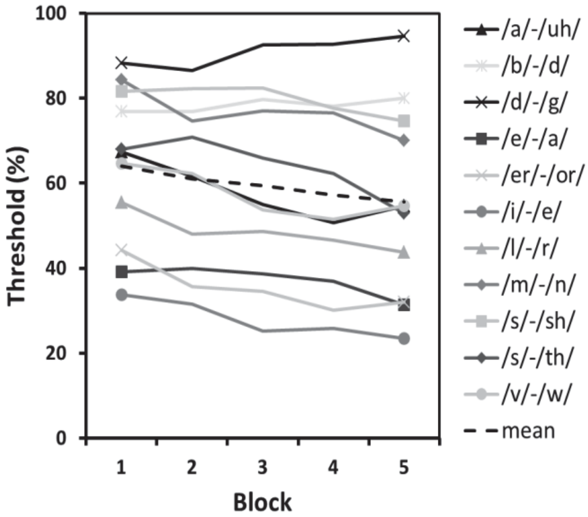

Fig. 2: Phoneme discrimination thresholds (across all participants) for each of the 11 phoneme continua over five training blocks; dashed line = group geometric mean.

(p = .855), and for /d/-/g/ performance got significantly worse ($p < .001$) over the course of training.

Transfer of learning to untrained measures

Identification of appropriate outcomes: competing speech

Analysis of performance for the competing-speech task across T1, T2, and T3 using a repeated measures ANOVA showed a significant main effect of time on speech reception thresholds ($F(2,28) = 3.59$, $p < .05$), see Fig. 3. Post-hoc comparisons showed no improvement for the control period (T1-T2), mean difference = −0.1, p = .89, and a significant improvement pre- to post-training (T2-T3), mean difference = 2.3 dB, $t(29) = 2.55$, p < .05, d = .47.

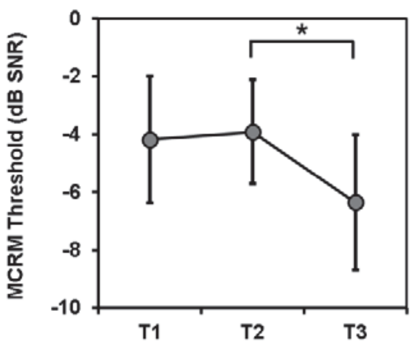

Fig. 3: Mean speech reception threshold (dB SNR) values for a two competing talker task (MCRM) with 95% confidence intervals at T1, T2, and T3, * $p < .05$.

Partial correlations controlling for age were used to explore the relationship between auditory and cognitive factors associated with performance on speech-perception tasks employed in either the present study (MCRM, two-competing-talker task), or in Ferguson *et al.*, in press (ASL sentences in 8-kHz modulated noise). Baseline pre-training measures at T1: better ear averaged hearing thresholds (BEA), self-reported listening (Initial Disability from the Glasgow Hearing Aid Benefit Profile), and working-memory (WM) scores (Digit Span forwards and backwards for Ferguson *et al.*, in press; Letter-Number Sequencing task for the present study), were correlated with baseline performance on the speech measures. Results are summarised in Table 1.

r =	BEA hearing thresholds	Self-reported listening	Working memory performance
Speech in noise (*n* = 44) (Ferguson *et al*, in press)	.38*	.08	.28
Competing speech (*n* = 30) (present study)	.49**	.45*	-.54**

Table 1: Partial correlations for baseline performance on speech-perception tasks (ASL sentences,) and (MCRM two competing talker task,), and baseline measures of better ear averaged hearing thresholds (BEA), self-reported listening, and working memory performance, * $p < .05$, ** $p < .01$.

Speech-perception performance on both tasks was significantly correlated with BEA hearing thresholds. Performance on the speech-in-noise task did not correlate significantly with self-reported listening or WM performance (Digit Span forwards and backwards). Performance on the competing speech task was significantly correlated with self-reported listening difficulties and with WM performance (Letter-Number Sequencing Task).

Identification of sensitive outcomes: dual-task of listening and memory

Individual task scores out of a possible 20 (number of digits correctly recalled and words correctly repeated) are plotted in Fig. 4.

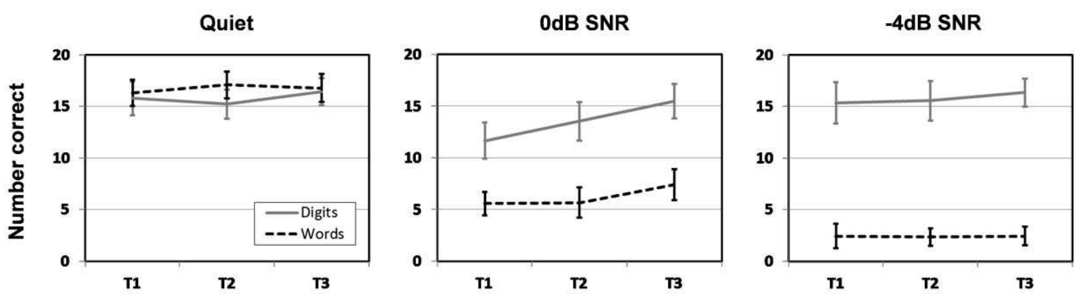

Fig. 4: Mean correct number of digits recalled and words repeated with 95% confidence intervals, across three noise conditions at T1, T2, and T3.

In quiet, performance was high for both the digit-recall and the word-repetition tasks. At 0 dB SNR, performance on the word-repetition task was reduced, with a reduction in performance for digit recall compared with the quiet condition. This may indicate an altered allocation of available resources to deal with the more difficult word-repetition demands. At −4 dB SNR, where participants were unable to identify the majority of words, digit-recall performance was once again comparable to that for the quiet condition.

Primary- and secondary-task scores were combined for each participant to give a dual-task score for each noise condition (maximum score = 40). A repeated-measures ANOVA showed no significant main effect of time on dual-task performance across the three noise conditions ($F(2,87) = 1.75$, $p = .177$), and no significant interaction between noise condition and time ($F(2,87) = 0.33$, $p = .719$). However, for the 0-dB SNR condition, where altered resource allocation was shown, there was a significant main effect of time on dual-task performance ($F(2,28) = 7.72$, $p = .001$). Post-hoc comparisons showed no improvement during the control period (T1-T2; mean difference = 0.2, $p = 1.00$), and a significant improvement pre- to post-training (T2-T3); mean difference = 3.6), $t(29) = -4.24$, $p < .001$, $d = .77$ (Fig. 5).

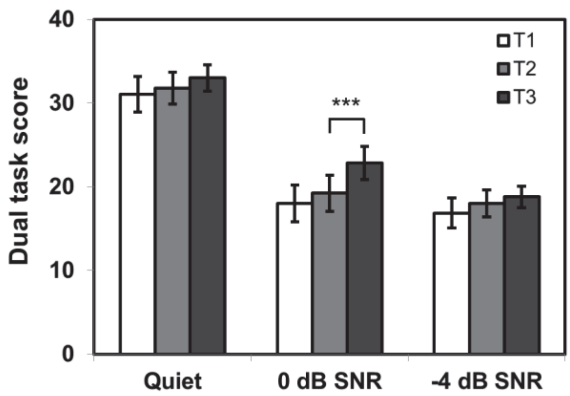

Fig. 5: Mean dual-task score for all participants with 95% confidence intervals across three noise conditions at T1, T2, and T3.

DISCUSSION

Results from the present study showed a significant improvement in phoneme-in-noise discrimination thresholds over time. The on-task learning effect was shown despite a substantially reduced AT schedule (just over half the training administered in Ferguson *et al.*, in press), and no significant improvements for three out of four of the trained phoneme continua with the poorest initial thresholds. As phoneme continua with the poorest initial thresholds improved the most during phoneme-discrimination-in-quiet training in the previous RCT (Ferguson *et al.*, in press), thus making the largest contribution to the on-task learning effect, it is likely that, these continua were too difficult for participants to discriminate when presented in a background of noise in the present study.

Despite a shorter auditory-training schedule and substantially less on-task learning than Ferguson *et al.,* (in press), generalised improvements were shown for a competing speech task that was associated with self-reported listening and cognitive abilities, and for a dual task of listening at a challenging SNR, but not where the task was too easy nor too difficult. These findings suggest that outcomes used to assess benefit of auditory training should be sensitive to the cognitive effects of training. Furthermore, benefits of training may be most evident when listening is challenging, and where resources need to be reallocated to meet listening demands. These results highlight a need for appropriate and sensitive outcomes to adequately assess the benefits of auditory training for people with hearing loss to ensure that those benefits are not overlooked.

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