Short-term auditory learning in older and younger adults

HANIN KARAWANI[1,2], LIMOR LAVIE[1], AND KAREN BANAI[1,*]

[1] *Department of Communication Sciences and Disorders, University of Haifa, Haifa, Israel*

[2] *Department of Hearing and Speech Sciences, University of Maryland, College Park, MD, USA*

Why speech perception in noise declines with aging remains under substantial debate. One hypothesis is that older adults adapt to perceptually-difficult listening conditions to a lesser extent than younger adults, and this, in turn, contributes to their difficulties. To test this hypothesis, we are conducting an ongoing study on the association between speech perception and perceptual learning. Here we compared the rapid learning of speech in noise between normal-hearing older and younger adults. All participants completed 40 minutes of training during which they listened to auditory passages embedded in adaptively-changing babble noise and answered content questions. To assess learning and transfer, participants were tested on the trained task and on two untrained tasks (pseudoword discrimination and sentence verification) before and after training. Both groups showed improvements over the course of the training session. Pre- to post-test improvements were observed on the trained task but not on either of the untrained ones. Consistent with the idea that poor rapid learning might limit perception in older adults, strong correlations were found between the amount of improvement during training and baseline performance of the untrained tasks.

INTRODUCTION

Aging negatively influences speech perception in noise even in individuals who maintain audiologically-normal hearing (e.g., Dubno *et al.*, 1984; Pichora-Fuller *et al.*, 1995). However, life-long experiences (e.g., playing a musical instrument) can partially offset this deleterious effect (Parbery-Clark *et al.*, 2011). Whether relatively short training protocols can yield similar effects is debated because the effects of such protocols in clinical populations are often disappointing (Henshaw and Ferguson, 2013). Improvements on perceptual tasks are variable across studies, and generalization effects, when shown, are not robust (e.g., Anderson *et al.*, 2013; Ferguson *et al.*, 2014; Karawani *et al.*, 2015). This could arise from age-related declines in perceptual learning, similar to the well documented deterioration in speech perception in noise. Because it is thought that one possible role of perceptual learning in 'real life' is to allow adaptation to challenging listening situations through rapid learning (Samuel and Kraljic, 2009), we are interested in the effects of age on this learning. The majority of previous studies

*Corresponding author: kbanai@research.haifa.ac.il

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investigated the effects of multi-session training protocols. Therefore, the effects of age on rapid learning and on the relationships between rapid learning and the recognition of perceptually-difficult speech are not well understood.

Thus, the goal of this study was twofold: (1) To directly compare learning between older and younger adults and to determine whether there are age-related declines; (2) To assess the pattern of correlations between perceptual learning in one task and performance in other speech in noise (SIN) tasks. Specifically, we asked whether poor perceptual learning in one trained task is associated with poor baseline performance in two other untrained tasks.

MATERIALS AND METHODS

Twenty-two older adults (17 females) aged 60–81 years (mean age: 70 years, SD: 5) and twenty-eight younger adults (18 females) aged 20–30 years (mean age: 25 years, SD: 3) volunteered to participate in the study. All participants were native Hebrew speakers, with no history of neurological disorders and with normal hearing. Hearing was defined as normal according to the World Health Organization criteria (4-frequency pure-tone average thresholds $\leq$ 25 dB HL). On the first session all participants underwent a series of three SIN tests (pre-test) and then immediately completed a 40-minute training session. They were tested again on the same series of tests on the next day (post-test). All tests and training stimuli were embedded in four-talker babble noise and presented via headphones. Noise and all stimuli were normalized to 70 dB SPL. This design replicates that of Karawani *et al*. (2015), except that brief training was administered here. Given the differences in SIN performances between younger and older adults (Dubno *et al.*, 1984; Lavie *et al.*, 2014), the initial signal-to-noise (SNR) ratios of each task differed between groups (see below), such that the older group started with a more favourable SNR than the younger group.

Pre- and Post-tests included SIN tests on the trained task (A. Passages test) to assess the learning effect, and on two other untrained tasks SIN (B. Pseudoword discrimination test and C. Sentence verification test) to assess generalization. A. Participants listened to thematic passages (e.g., about energy conservation) taken from popular science articles (specific details can be found in Karawani *et al.*, 2015) and embedded in noise, and were asked to answer visually-presented multiple choice questions related to the content of the passage. Passages were 6-9 minutes long and a question was presented every 2-3 sentences. The initial SNR value of the test was +10 dB for older participants and 0 dB for younger participants. Mean SNR thresholds (in dB) were calculated for each participant. B. Pseudoword discrimination: Participants performed a same/different discrimination task in which 60 pairs of two-syllable pseudowords embedded in noise were presented aurally by a native female speaker, with equal numbers of "same" and "different" trials (e.g., "same": /damul/-/damul/, "different": /malud/-/maluk/), with equal number of pairs from each phonetic contrast and vowel template (for details see Karawani *et al.*, 2015). Discrimination thresholds (in dB) were calculated for each listener from the staircase data. C. The sentence verification test required listeners to make plausibility judgments on 60 simple sentences (e.g., "The young child climbed the high tree.") embedded in noise. After hearing a sentence, listeners had to determine whether the sentence was semantically plausible ("true") or not ("false"). Mean SNR thresholds were calculated for each participant from the staircase data. Both pseudoword discrimination and sentence verification tests were administered with a starting SNR value of +5 dB for older adults (similar to Karawani *et al.*, 2015) and 0 dB for younger participants. SNR levels then were adapted by steps of 1.5 dB based on their responses with a 2-down/1-up adaptive staircase procedure. Across tasks, visual feedback was provided for both correct and incorrect responses. 4-talker babble noise was used for all tasks. Participants completed all tasks by making their decisions through a computer interface which recorded their responses and calculated the thresholds.

SIN training included seven blocks of training on passages embedded in 4-talker babble noise (similar to the passages task used in the pre- and post-tests, but with passages on different topics). An adaptive 2-down/1-up staircase procedure was used to adjust the level of difficulty to the performance of each listener based on their individual performance. The adaptive parameter was the SNR, where the noise level changed by 1.5 dB. Mean SNR thresholds of each block was calculated for each participant. The intensity level of the signal at the initial presentation of the first block was 10 dB greater than that of the noise (+10 dB SNR) for older participants. For younger participants the starting SNR was 0 dB. Improvement with training is reflected by a reduction in the threshold, suggesting that as training progressed listeners could maintain a good level of accuracy even with a more "difficult" (lower quality) stimulus. For each listener, the starting SNR for each block of training was based on the SNR at the end of the previous block.

RESULTS

Learning following brief training

Training effects across the seven training blocks were analysed for each group separately (Fig. 1A). To enable comparisons between groups with different starting SNRs, "normalized" scores were used. For each participant SNRs were adjusted such that block 1 values were fixed to 0. Then, for each subsequent block, SNR was presented as the difference (in dB) from block 1. To determine whether participants improved during training, linear curve estimation was performed on the group data across blocks (Fig. 1B). These analyses revealed a good fit of the linear curves to the data with significant R-squared values suggesting that a linear improvement across blocks accounts for a significant amount of the variance in performance [younger: $R^2 = 0.578$, $F(1,5) = 6.84$, $p = 0.04$; older: $R^2 = 0.934$, $F(1,5) = 70.92$, $p < 0.0001$]. To compare the amount of training-induced changes between groups, the linear slopes of the individual learning curves were calculated for each participant. Mean slopes were significantly negative in both younger and older groups. Although visual inspection of the learning curves show steeper slopes in the older than in the younger group, this was not statistically significant [older: $a = -1.54$; 95% CI: −2.23, −0.674; younger: $a = -0.79$; 95% CI: −1.26, −0.32; $t(48) = 1.56$, $p = 0.124$]. The younger group show some insignificant deterioration towards the end of training. We are not sure whether this deterioration might be due to lack of concentration, boredom or poor motivation of the young adults.

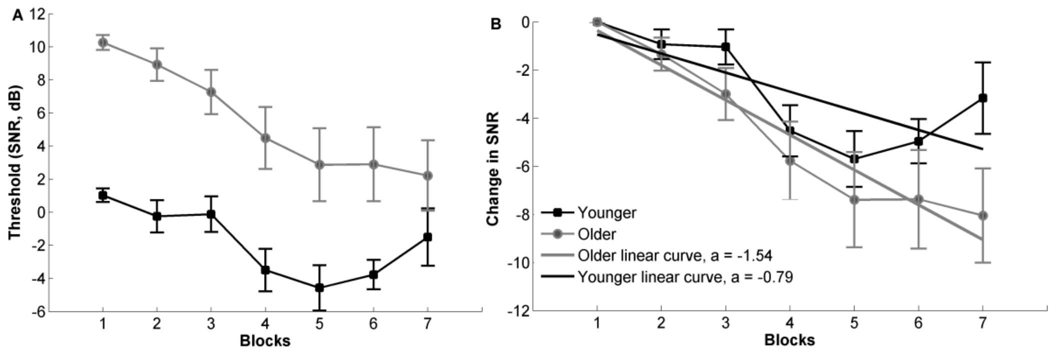

Fig. 1. A. Learning curves. Thresholds as a function of the trained block for younger (black squares) and older (grey circles) trainees are shown. **B. Adjusted learning curves.** Regression lines and slopes of the learning curves for younger (black linear lines) and older (grey linear lines) are also shown. Error bars reflect standard errors of the mean.

Pre-to-post training changes

Paired samples *t*-tests were conducted on each test to determine whether training-induced learning occurred on trained and untrained tasks (Table 1). Since the initial starting values differed between groups (see Materials and Methods), each group was analysed separately. Pre- to post-test changes (reflecting training effects) were observed only for the passages test with significant effects in both the younger and the older groups [younger: $t(27) = 4.16, p < 0.001$; older: $t(21) = 2.131, p = 0.04$]. On the other hand, no significant changes between pre- and post-sessions were shown for either the pseudoword discrimination or the sentence verification tests [pseudoword discrimination: younger: $t(27) = 0.11, p = 0.92$; older: $t(21) = 0.78, p = 0.44$; sentence verification: younger: $t(27) = 0.74, p = 0.47$; older: $t(21) = 0.68, p = 0.50$]. In order to compare the amount of change between groups in the passages tests, independent *t*-test analysis was conducted on the difference between the pre- and post-test values (calculated as the post threshold minus the pre threshold for each participant). No significant difference was observed between groups [$t(48) = 0.42, p = 0.68$; mean difference younger = −2.17, SD = 2.76; mean difference older = −1.78, SD = 3.91].

Correlation effects

The correlations (with *r* and *p* values) between the rapid learning and the three pre-test measures are shown in Fig. 2. Rapid learning over the course of training was calculated as the difference between the last and the first training blocks. The results show that older participants who improved less over the course of training also had poorer starting performance on the trained task ($r = 0.49$) and on the two untrained SIN tasks – pseudoword discrimination ($r = 0.57$) and sentence verification ($r = 0.66$). This is consistent with the idea that declines in rapid learning might limit perception. The correlations were not significant in the younger group even when re-calculated after the exclusion of the participants that improved the least during training (the rightmost data point on each panel of Fig. 2).

	Passages		Pseudoword Discrimination		Sentence Verification	
	pre	**post**	**pre**	**post**	**pre**	**post**
Younger	0.25 (0.47)	-0.92 (0.36)	-1.48 (0.48)	-0.55 (0.52)	-2.11 (0.52)	-2.53 (0.50)
Older	8.83 (0.68)	7.06 (0.58)	4.37 (0.98)	3.50 (0.99)	2.80 (1.27)	3.43 (1.54)

Table 1. Mean performance (with standard error of the mean, SEM) in younger and older participants, in the pre- and post-test for the Passages test, Pseudoword Discrimination and Sentence Verification tests.

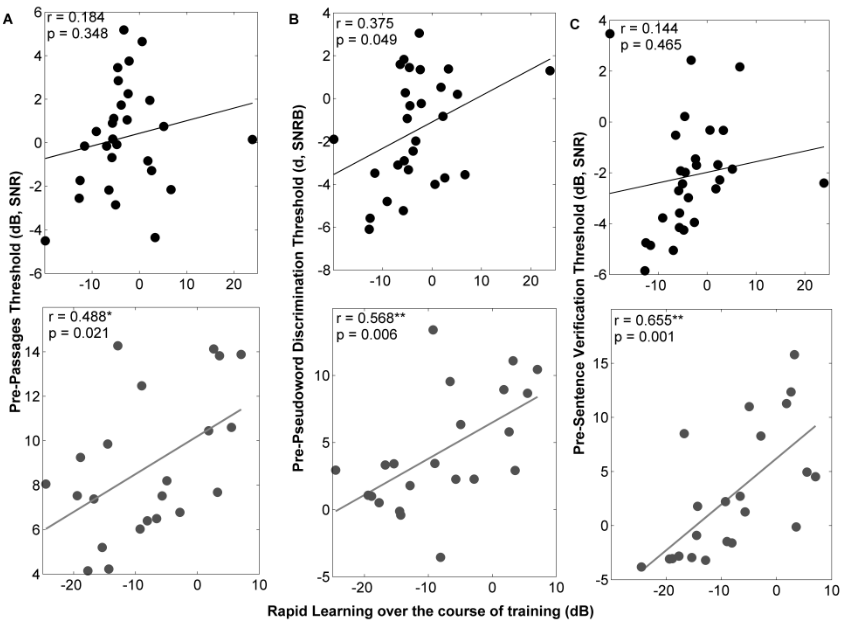

Fig. 2. Pre-test performance as a function of learning during training. A. Passage test, B. Pre-pseudoword discrimination test, and C. Sentence verification test, for younger (black dots, top row) and older (grey dots, bottom row) participants. Pearson correlation coefficient values (*r*) and *p* values are shown for each graph; * $p < 0.05$, ** $p < 0.01$.

If the amount of rapid perceptual learning explains how well an individual should do under difficult perceptual conditions, then rapid learning on the trained task should account for unique variance in the performance of the other tasks, even after we take into account the potential correlations between the different pre-test assessments of SIN. To test this idea, we used regression models to predict baseline performance on each of the untrained tasks using the amount of learning over the training session and baseline performance on the passages test as predictors. Table 2 shows that in older adults, initial performance on the passages test and rapid learning account for 34% of the variance in pre-test pseudo-words discrimination. Out of these, 30% were attributed to rapid learning. The same predictors also account for 48% of the variance in initial sentence verification, and 47% can be attributed to learning.

		R^2	R^2 change	F_{change}	df1,df2	p
Pseudoword discrimination	**Younger**	0.15	0.12	3.62	1,25	0.069
	Older	0.34	0.30	8.66	1,19	0.008
Sentence verification	**Younger**	0.02	0.02	0.46	1,25	0.502
	Older	0.48	0.47	17.19	1,19	0.001

Table 2. Regression models: Speech perception in noise predicted by rapid learning. R^2 (for full model), R^2 change (following the addition of rapid learning), F-values with degrees of freedom and p-values are presented across pre-test measures for younger adults and older adults groups.

DISCUSSION

The present study compared the effects of a short-term SIN training on speech perception between normal-hearing younger and older adults. The effects of age and the relationships between rapid learning in one task and performance in other SIN tasks were assessed. The major outcomes of the current study were: (i) Robust training-induced learning effects were found in both younger and older adults. (ii) Learning patterns were similar between younger and older adults. Although this could stem from the deterioration in performance of the younger group towards the end of training we do not think this is the case because the slopes of the learning curves appear similar even when based on fewer training blocks. Furthermore, deterioration of performance towards the end of training is not unique to the current study (see Karawani *et al.*, 2015 for another example) and is typically thought to reflect boredom or the expectation to finish training. (iii) Performance improvements were specific to the trained task with no transfer of learning to either of the untrained tasks (pseudowords and sentences in noise). (iv) Finally, the amount of improvement during training was significantly correlated to the starting performance of the untrained tasks in older adults even when the correlations between different measures of SIN were accounted for. Together, these findings suggest that rapid learning remains robust in normal-hearing older adults. Consistent with the outcomes of longer training protocols (e.g., Karawani *et al.*, 2015), generalization was limited.

Although correlation does not suggest causation, the current findings (Table 2) raise the intriguing possibility that perceptual difficulties could arise as a result of less than optimal rapid learning mechanisms. This is consistent with the view that perceptual learning serves to allow for rapid adaptation to changing acoustic circumstances (Samuel & Kraljic, 2009). Since the link between baseline SIN measures and rapid learning was robust in older adults, we suggest that the relationships between rapid learning and full training programs should be assessed because according to this idea, training will only be useful if it contributes to rapid learning in changing acoustic environments. The rich literature available on aging suggests that many behavioural and neural processes change with aging. Age-related declines have been documented in hearing, vision (e.g., Baltes and Lindenberger, 1997) and cognitive processing (e.g., Birren, 1970) such as working memory (e.g., Lyons-Warren *et al.*, 2004), attention (e.g., Kramer and Madden, 2008), executive function (Zelazo *et al.*, 2004), reasoning abilities (e.g., Salthouse, 2005), processing speed (Salthouse, 1996) and other factors. While the comprehension of the meaning of words is typically well-preserved in older age, older adults generally have difficulties understanding spoken language that is distorted (Wingfield and Grossman, 2006), especially by background noise (Schneider *et al.*, 2002). These factors are all important to new learning (Park and Reuter-Lorenz, 2009). It was shown that the ability to learn new outcome contingencies declines over the course of healthy aging (Burke and Barnes, 2006), and that explicit and implicit learning declines in the course of normal aging (Howard Jr and Howard, 2013). However, while younger and older listeners show the same amount of learning in the initial adaptation phase, older listeners' performance plateaus earlier in adapting to unfamiliar speech (Peelle and Wingfield, 2005). Older adults show less transfer of learning to similar conditions (Peelle and Wingfield, 2005) and exhibit slower consolidation of learning (Sabin *et al.*, 2013).

In conclusion, against the declines in learning described above, this study shows that when SNRs are selectively chosen to account for age-related differences in SIN perception, the rapid learning that follows short-term SIN training is still robust in older adults. It is interesting that older participants who improved less over the course of training also had poorer starting performance on the trained task as well as poorer performance on untrained SIN tasks. Future work should thus attempt to decipher the reciprocal relations between perception and learning. If good perception is pre-requisite for robust learning, training is likely to fail those listeners who need it most. On the other hand, if rapid learning contributes to the perception of perceptually-difficult speech by making individuals with better rapid learning skills more adept at adjusting to ever-changing acoustic environments, we need to consider the effects of available longer-term training programs on this rapid learning.

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