Effects of auditory training on low-pass filtered speech perception and listening-related cognitive load

Matthew G. Wisniewski, and Alexandria C. Zakrzewski

ARTICLES YOU MAY BE INTERESTED IN

Effects of auditory training on low-pass filtered speech perception and listening-related cognitive load

Matthew G. Wisniewski[a)] and **Alexandria C. Zakrzewski[b)]**

Department of Psychological Sciences, Kansas State University, 1114 Mid-Campus Drive North
mgwisniewski@ksu.edu, aczakrzewski@ksu.edu

Abstract: Studies supporting learning-induced reductions in listening-related cognitive load have lacked procedural learning controls, making it difficult to determine the extent to which effects arise from perceptual or procedural learning. Here, listeners were trained in the coordinate response measure (CRM) task under unfiltered (UT) or degraded low-pass filtered (FT) conditions. Improvements in low-pass filtered CRM performance were larger for FT. Both conditions showed training-related reductions in cognitive load as indexed by a secondary working memory task. However, only the FT condition showed a correlation between CRM improvement and secondary task performance, suggesting that effects can be driven by perceptual and procedural learning. © *2020 Acoustical Society of America*

1. Introduction

Degraded listening conditions can decrease speech comprehension accuracy and make listening feel excessively effortful (McGarrigle *et al.*, 2014; Strauss and Francis, 2017). This is commonly observed in individuals with hearing loss (e.g., Bernarding *et al.*, 2013; Downs, 1982; Mishra *et al.*, 2014), but degraded conditions produced by poor quality cell phone speakers (Rakauskas *et al.*, 2004), rooms with long reverberation times (Rennies *et al.*, 2014), and hearing protection devices (Smalt *et al.*, 2020) can yield similar detriments. The current work evaluates auditory training's potential for improving speech comprehension accuracy and reducing cognitive load under such degraded listening conditions.

Beneficial impacts of auditory training on speech perception have received a decent amount of attention in the literature (for review, see Samuel and Kaljic, 2009). Most studies, however, have focused on unrealistic listening tasks such as phoneme discrimination (e.g., Clarke-Davidson *et al.*, 2008) and lexical decision (e.g., Norris *et al.*, 2003). Fewer have investigated learning under conditions of signal degradation. Of these, training has been shown to improve performance with speech degraded via temporal compression (Banai and Lavner, 2012), shifting of pitch range (Fu and Galvin, 2007), vocoding (Hervais-Adelman *et al.*, 2011), the addition of masking noise (Spencer *et al.*, 2016), and interruptions to speech (Benard and Baskent, 2013). Still, the impacts of training on listening-related cognitive load have received little attention. Sommers *et al.* (2015) trained listeners to perform various phoneme discrimination and speech comprehension tasks masked by 4-talker babble. Pre- and post-tests entailed a modified *N*-back task with masked speech. Memory for 3-back words significantly improved form pre- to post-test, suggesting that training had yielded more spare capacity to retain words in memory after comprehension was completed (i.e., a reduction in cognitive load; McCoy *et al.*, 2005). Using pupillometry, Kuchinsky *et al.* (2014) gave listeners training with word recognition in noise and found that training yielded changes in the pupil's response to word presentations. However, neither study used a control group for procedural learning, making it difficult to conclude that effects reflected more than learning the demands of tasks and experimentation in general. Further, Kuchinsky *et al.* (2014) found that training yielded an increase in pupil diameter. Such an effect has frequently been associated with increased, not decreased, cognitive load (Borghini and Hazan, 2018; Miles *et al.*, 2017; Piquado *et al.*, 2010; Strand *et al.*, 2018; Zekveld *et al.*, 2014).

Here, we used the coordinate response measure (CRM) task (Bolia *et al.*, 2000; Thompson *et al.*, 2015) combined with a secondary melody comparison task to form a dual-task listening scenario. Performance on primary (CRM) and secondary (melody comparison) tasks were assessed before (pre-) and after (post-) a period of training. CRM stimuli in the test were degraded with low-pass filtering to simulate the attenuation created by common hearing

---
[a)]Author to whom correspondence should be addressed.
[b)]ORCID: 0000-0002-0169-2761.

protection devices, which yields poorer speech perception accuracy and greater listening-related cognitive load (Gallagher *et al.*, 2014; Reddy *et al.*, 2014; Smalt *et al.*, 2020). For training, individuals performed the CRM under conditions of low-pass filtering (filtered training; FT) or no filtering (unfiltered training; UT). Note that the UT condition received training on the relevant task procedures and with speech-on-speech masking, but was not exposed to low-pass filtered speech. We hypothesized that FT would improve CRM performance and decrease cognitive load as indexed by better secondary task performance in the post-test. Since the difference between UT and FT conditions was whether or not test-relevant low-pass filtered stimuli were heard in training, FT improvements above that of the UT condition were expected to stem from perceptual learning specific to low-pass filtering conditions.

2. Methods

2.1 Participants

Forty-one individuals at Kansas State University participated for course credit. All self-reported normal hearing. Procedures were approved by the local ethics committee and all participants signed an informed consent document. One participant was dropped from the UT condition for exceptionally poor single-task CRM performance (<15% correct). The final sample contained 20 individuals in each training condition (FT, UT).

2.2 CRM task

The employed CRM corpus contains spoken sentences of the form "Ready <call sign>, go to <color> <number> now" (for details, see Bolia *et al.*, 2000; Thompson *et al.*, 2015). Here, we used eight talkers (four female), eight call signs (Arrow, Baron, Charlie, Eagle, Hopper, Laker, Ringo, Tiger), four colors (red, blue, white, green), and four numbers (1–4). On each trial, listeners were presented with a CRM sentence with the "Baron" call sign spoken by one of four randomly selected male talkers. A female (i.e., different sex) spoken masker sentence with one of the other call signs was presented at a 0 dB target-to-masker ratio. The talkers, masker call sign, colors, and numbers were selected randomly for each trial, with replacement occurring across trials. Listeners were tasked to indicate the color/number of the "Baron" sentence. Depending upon the condition and block within the experiment, CRM stimuli were either left unfiltered,[1] or digitally low-pass filtered with a finite impulse response (FIR) filter having a passband edge of 20 Hz and a stopband attentuation of –60 dB. The stopband edge was either 1048, 532, 276, or 148 Hz, creating filters with relatively shallow to relatively steep roll-offs. These filter settings were chosen because the 148 Hz stopband mimics the attenuation that occurs with use of standard hearing protection devices (Gallagher *et al.*, 2014). Other filters allowed training with an easy-to-hard progression known to induce strong perceptual learning effects (e.g., Church *et al.*, 2013; Wisniewski *et al.*, 2017a; Wisniewski *et al.*, 2019).

2.3 Melody comparison task

Before and after the presentation of CRM sentences, listeners could be presented with four note sequences made up of pure tones (400 ms, 20 ms on- and off-ramps) mapping onto musical notes A3–A4 (f0 range of 220–440 Hz). The 1st and 2nd sequences were spaced 500 ms from the onset and offset of CRM sentence presentation. On each such trial, notes were selected at random (with replacement) for the sequence presented before the CRM. Half of trials were "Same," in which the second sequence was the same as the first. Half were "Different," with the second sequence having one randomly selected note replaced with a different note in the range of A3–A4 (also selected at random). Participants were tasked with indicating whether the melodies were the same or different. Figure 1(a) depicts an example waveform representing the combination of the CRM with the melody comparison task. The task was chosen because of its potential generalizability to non-speech studies and to avoid ambiguity in regard to whether listeners are prioritizing memory content or listening to speech in tasks like an *N*-back.

2.4 Apparatus

Sounds were presented using Focusrite Scarlett audio interfaces (Focusrite, UK) and Sennheiser HD-280 closed-back headphones (Sennheiser, Germany). Listeners sat in sound-attenuating listening booths (WhisperRoom, Knoxville, TN). Sound levels did not exceed 79 dB sound pressure level (SPL). Procedures were controlled with MATLAB (Natick, MA). Responses were made with custom X-Keys response pads (P.I. Engineering, Williamston, MI).

2.5 Design and procedures

A 2 (training condition: UT vs FT) × 2 (task condition: Single vs Dual) × 2 (test: pre-, post-test) mixed design was used [see Fig. 1(b)]. Task condition and test were within-subject factors. An
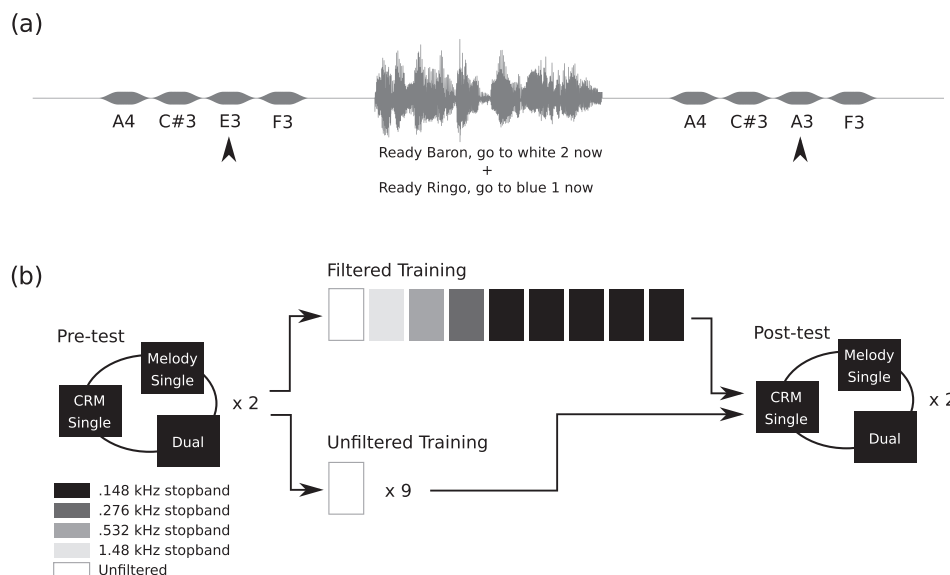
(a)

(b)

Fig. 1. (a) Depiction of audio from an example trial where the CRM task is combined with the melody comparison task. Arrows highlight the note within the melodies that changes from before to after the CRM sentence presentation. (b) Illustration of the design and procedures used.

individual's participation always occurred on three consecutive days. Pre- and post-tests were on Day 1 and Day 3. Training was on Day 2.

Testing was identical for the UT and FT conditions. In the pre- and post-tests, there were three types of blocks: *Single CRM*, *Single Melody*, and *Dual*. For each block type, listeners were exposed to stimuli similar to that shown in Fig. 1(a). In *Single CRM* blocks, listeners were tasked to respond with the color/number pair of the "Baron" sentence using the response pad with a 4×4 grid of color/number options. In *Single Melody* blocks, they were instead prompted to report their same/different judgment with other keys on the same response pad. In *Dual* blocks, listeners performed both tasks, reporting the color/number pair, then the same/different judgment. Instructions were to prioritize the CRM in *Dual* blocks. To promote prioritization of the CRM, a penalty timeout (8 s) was given when an incorrect response was made on the CRM (for all blocks, conditions, and days). For *Dual* blocks, this penalty was incurred after responding to the melody comparison task. Further, feedback was only presented for the CRM and never for the melody comparison task. Listeners were told which type of block they were about to perform before starting a block. The reasons for the different block types were to assess dual-task cost for the CRM and melody comparison. There were two blocks per type, containing 20 trials each, and pseudorandomly ordered such that the second encounter with a block type did not come before all block types were experienced at least once. Ten seconds were given to respond to each prompt before a timeout occurred. All testing employed CRM sentences filtered with the most difficult 148 Hz stopband edge.

Training for both conditions entailed nine blocks (20 trials per block) of the CRM without melody comparison stimuli, all with feedback after responding. "Correct" or "Wrong" was displayed on screen, along with the 8 s timeout if responses were wrong. For the UT condition, trials employed unfiltered CRM stimuli. The FT condition did the same, except that the stopband edges of filtering decreased over the course of blocks in an easy-to-hard progression [see Fig. 1(b) for specific progression].

3. Results

3.1 CRM accuracy

UT (M = 0.94, SD = 0.06) and FT (M = 0.92, SD = 0.05) proportion correct was similar during training (across all trials), with no significant difference between conditions, $t < 1$. Thus, large differences in the difficulty of training were not evident.

Test proportion correct data (color and number) are shown in Fig. 2(a). Analysis entailed a mixed model 2 (training condition: FT, UT) $\times$ 2 (task condition: single, dual) $\times$ 2 (test: pre-, post-test) analysis of variance (ANOVA) using Greenhouse-Geisser corrections to degrees of freedom before interpreting significance (uncorrected *df*s reported). Both the UT and FT conditions appeared to improve from pre- to post-test (M$_{pre}$ = 0.82, SD$_{pre}$ = 0.12; M$_{post}$ = 0.90, SD$_{post}$ = 0.06), supported by a main effect of test, $F(1,38) = 24.63$, $p < 0.001$, partial eta^2 = 0.38.
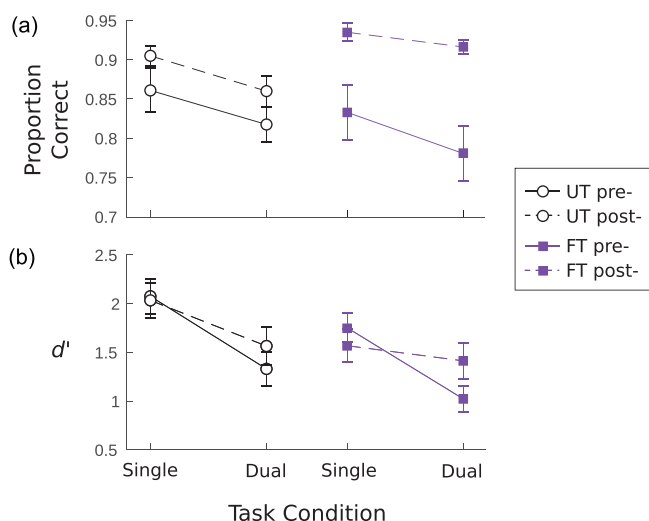
Fig. 2. (Color online) (a) Accuracy for the CRM task. (b) d' for the melody comparison task. Error bars show standard errors of the mean.

However, there was also a significant training condition x test interaction, $F(1,38) = 5.35$, $p = 0.026$, partial eta$^2 = 0.15$. Independent sample t-tests comparing the pre- and post-test data for the UT and FT conditions found a difference in the post-test ($M_{UT} = 0.88$, $SD_{UT} = 0.07$; $M_{FT} = 0.93$, $SD_{FT} = 0.03$), $t(38) = 2.53$, $p = 0.015$, Cohen's $d = 0.80$. There was no difference in the pre-test, $t < 1$. Thus, FT yielded accuracy improvements above and beyond that accountable by procedural learning and any perceptual learning of general speech-on-speech masking. There was also a main effect of task, $F(1,38) = 15.44$, $p < 0.001$, partial eta$^2 = 0.27$, indicating a cost to performing the CRM under the dual-task scenario ($M_{single} = 0.88$, $SD_{single} = 0.09$; $M_{dual} = 0.84$, $SD_{dual} = 0.08$). Other main effects and interactions were not significant, Fs < 2.

3.2 Melody comparison accuracy

The d' signal detection parameter was used as a measure of accuracy to minimize impacts of any biases to respond "same" or "different." Figure 2(b) shows d' for each test, training, and task condition. There was a main effect of task condition, $F(1,38) = 52.04$, $p < 0.001$, partial eta$^2 = 0.58$, such that the dual task had lower d' than the single-task condition ($M_{single} = 1.86$, $SD_{single} = 0.67$; $M_{dual} = 1.33$ $SD_{dual} = 0.65$). This indicated the expected dual-task cost. There was also a significant task condition x test interaction, $F(1,38) = 6.33$, $p = 0.016$, partial eta$^2 = 0.14$, likely related to better performance for the dual-task melody comparison after training ($M_{pre} = 1.18$, $SD_{pre} = 0.70$; $M_{post} = 1.49$, $SD_{post} = 0.85$). Indeed, dual-task d' was significantly lower in the pre- than the post-test, $t(39) = 2.28$, $p = 0.028$, Cohen's $d = 0.36$. Single-task d', did not differ between pre- and post-test, $t < 1$. All other main effects and interactions were not significant, Fs < 2.

We next performed a correlational analysis (cf. Sommers *et al.*, 2015) to examine the relationship between gains in CRM accuracy and reductions in cognitive load as quantified by dual-task melody comparison d'. Figure 3 shows scatterplots of individual improvements on the CRM (x axis; post-test minus pre-test) and improvements in dual-task melody comparison d' (y axis; post-test minus pre-test). The UT condition did not show any significant relationship between CRM gains and gains in dual-task melody comparison performance, $r(18) = 0.03$, $p = 0.903$. The FT condition did show a significant positive correlation, $r(18) = 0.68$, $p < 0.001$. To compare r values between conditions, we used a surrogate distribution of r values by randomly assigning condition labels to data for 1000 permutations. A p value for the observed r difference was then determined by calculating the proportion of r differences in the surrogate distribution being larger than the observed value. The difference in r was found to be greater than that expected by chance, $p = 0.030$. Thus, improvements on the CRM were related to reductions in cognitive load, but only in the condition that received relevant training with low-pass filtered speech.

4. Discussion

This study aimed to assess auditory training's impact on perception of low-pass filtered speech, and the cognitive load required for comprehension. Main findings were as follows: (1) FT
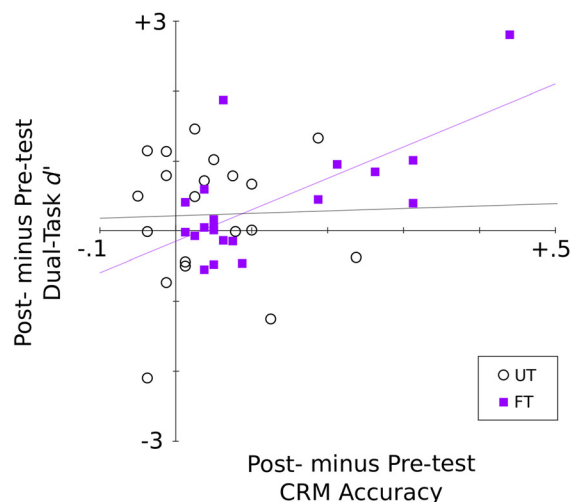
Fig. 3. (Color online) Scatterplot of improvement in dual-task melody comparison task accuracy (y axis) as a function of improvements to CRM task accuracy (x axis). Lines show least-squares fit to the UT and FT data.

improved accuracy beyond that produced by UT, (2) training yielded a decrease in CRM-related cognitive load regardless of training condition, and (3) CRM accuracy improvements were correlated with reductions in cognitive load, but only for the FT condition. Our data shows that some apparent reductions in cognitive load can come from procedural learning, or some generalizable perceptual learning for similar masking tasks. It will be necessary to address this possibility in training work going forward. However, that a relationship between extent of learning and cognitive load reductions was only observed in the FT group suggests that there is also a perceptual learning component specific to the trained acoustic conditions. Extent of learning only appears to matter for individuals receiving the test-relevant signal degradation.

The low-pass filtering used here produces attenuation similar to that produced by hearing protection devices (Gallagher *et al.*, 2014). Interestingly, poor speech understanding and excessive effort are chief reasons given by individuals for not wearing hearing protection (Reddy *et al.*, 2014; Smalt *et al.*, 2020). Hearing-protection related training programs for workers typically do not entail listening training, but conceptual training focused on the benefits of using hearing protection (Hong and Csaszar, 2005; Lusk *et al.*, 1995; Neitzel *et al.*, 2008; Trabeau *et al.*, 2008). Given that we show training-related benefits to perception and cognitive load, it may be useful to include perceptual training in such programs. Further, this would be a way to address the problems that come with hearing-loss (e.g., excessive listening effort) preemptively by reducing hearing-loss likelihood.

The current data also suggest that training can serve as a means to improve multi-tasking performance. This can be important for operators needing to listen under specific types of degraded conditions. For instance, military operators listening through a specific hearing protection device to specific types of low-bandwidth signals, or in environments with unique spectral characteristics, could receive appropriate listening training. Cognitive control of resource allocation, the making of confidence and error monitoring judgments, decision making, and prediction have effortful components that are important for guiding our behavior in complex scenarios (for review, see Schwartz, 2008; Yeung and Summerfield, 2012). Relief on the cognitive load needed to perform speech comprehension may yield more resources for these important processes and increase operator situational awareness and performance.

Though this work is promising in regard to hearing-loss prevention, rehabilitation, and performance enhancement, extensions will be needed to further progress training-related strategies. Any worthwhile training regimen needs to yield generalization beyond the circumstances of training. Future work will need to examine generalization of learning to untrained tasks and novel talkers. We employed a single-talker masker having a different sex than the target talker, showing effects in a largely informational masking scenario (i.e., target/masker content overlapped, but talker sex differed). More work is needed to evaluate impacts of training on informational *and* energetic masking, both of which are problems in the context of degraded speech listening. Relatedly, the use of different dual-tasks can yield different conclusions regarding cognitive load during listening (Strand *et al.*, 2018), perhaps because different measures tap into different cognitive resources (Strauss and Francis, 2017). Future research can yield more detail regarding learning's impacts by using measures that more clearly map onto specific

resources (e.g., Wisniewski, 2017; Wisniewski *et al.*, 2017b). It is also possible that effects observed here could be larger if training entailed multiple sessions (cf. Sommers *et al.*, 2015), or if training regimen parameters were optimized (e.g., Wisniewski *et al.*, 2019). Future work will benefit from exploring how the length and content of training can be altered to maximize learning's beneficial outcomes. The current data tells us that these are worthwhile research directions and that auditory training should be given more attention for its potential benefits.

Acknowledgments

References and links

[1]The employed corpus recordings were already bandpass filtered (80–8,000 Hz; Bolia *et al.*, 2000).

Banai, K., and Lavner, Y. (**2012**). "Perceptual learning of time-compressed speech: More than rapid adaptation," PLoS One **7**, e47099.

Benard, M. R., and Baskent, D. (**2013**). "Perceptual learning of interrupted speech," PLoS One **8**, e58149.

Bernarding, C., Strauss, D. J., Hannemann, R., Seidler, H., and Corona-Strauss, F. I. (**2013**). "Neural correlates of listening effort related factors: Influence of age and hearing impairment," Brain Res Bull **91**, 21–30.

Bolia, R. S., Nelson, W. T., Ericson, M. A., and Simpson, B. D. (**2000**). "A speech corpus for multitalker communications research," J. Acoust. Soc. Am. **107**, 1065–1066.

Borghini, G., and Hazan, V. (**2018**). "Listening effort during sentence processing is increased for non-native listeners: A pupillometry study," Front Neurosci **12**, 152.

Church, B. A., Mercado, E., Wisniewski, M. G., and Liu, E. H. (**2013**). "Temporal dynamics in auditory perceptual learning: Impact of sequencing and incidental learning," J. Exp. Psychol. Learn. Mem. Cogn. **39**, 270–276.

Clarke-Davidson, C. M., Luce, P. A., and Sawusch, J. R. (**2008**). "Does perceptual learning in speech reflect changes in phonetic category representation or decision bias?," Percept Psychophys **70**, 604–618.

Downs, D. W. (**1982**). "Auditory brainstem response testing in the neonatal intensive care unit: A cautious response," ASHA **24**, 1009–1015.

Fu, Q. J., and Galvin, J. J. III (**2007**). "Perceptual learning and auditory training in cochlear implant recipients," Trends Amplif **11**, 193–205.

Gallagher, H. L., McKinley, R. L., Theis, M. A., Swayne, B. J., and Thompson, E. R. (**2014**). "Performance assessment of passive hearing protection devices," U.S. Air Force Technical Report: AFRL-RH-WP-TR-2014-0148.

Hervais-Adelman, A. G., Davis, M. H., Johnsrude, I. S., Taylor, K. J., and Carlyon, R. P. (**2011**). "Generalization of perceptual learning of vocoded speech," J. Exp. Psychol. Hum. Percept. Perform. **37**, 283–295.

Hong, O., and Csaszar, P. (**2005**). "Audiometric testing and hearing protection training through multimedia technology," Int. J. Audiol. **44**, 522–530.

Kuchinsky, S. E., Ahlstrom, J. B., Cute, S. L., Humes, L. E., Dubno, J. R., and Eckert, M. A. (**2014**). "Speech-perception training for older adults with hearing loss impacts word recognition and effort," Psychophysiology **51**, 1046–1057.

Lusk, S. L., Ronis, D. L., and Kerr, M. J. (**1995**). "Predictors of hearing protection use among workers: Implications for training programs," Hum Factors **37**, 635–640.

McCoy, S. L., Tun, P. A., Cox, L. C., Colangelo, M., Stewart, R. A., and Wingfield, A. (**2005**). "Hearing loss and perceptual effort: Downstream effects on older adults' memory for speech," Q. J. Exp. Psychol. A **58**, 22–33.

McGarrigle, R., Munro, K. J., Dawes, P., Stewart, A. J., Moore, D. R., Barry, J. G., and Amitay, S. (**2014**). "Listening effort and fatigue: What exactly are we measuring? A British Society of Audiology Cognition in Hearing Special Interest Group 'white paper,'" Int. J. Audiol. **53**, 433–440.

Miles, K., McMahon, C., Boisvert, I., Ibrahim, R., de Lissa, P., Graham, P., and Lyxell, B. (**2017**). "Objective assessment of listening effort: Coregistration of pupillometry and EEG," Trends Hear **21**, 1–13.

Mishra, S., Stenfelt, S., Lunner, T., Rönnberg, J., and Rudner, M. (**2014**). "Cognitive spare capacity in older adults with hearing loss," Front Aging Neurosci **6**, 96.

Neitzel, R., Meischke, H., Daniell, W. E., Trabeau, M., Somers, S., and Seixas, N. S. (**2008**). "Development and pilot test of hearing conservation training for construction workers," Am. J. Ind. Med. **51**, 120–129.

Norris, D., McQueen, J. M., and Cutler, A. (**2003**). "Perceptual learning in speech," Cogn Psychol **47**, 204–238.

Piquado, T., Isaacowitz, D., and Wingfield, A. (**2010**). "Pupillometry as a measure of cognitive effort in younger and older adults," Psychophysiology **47**, 560–569.

Rakauskas, M. E., Gugerty, L. J., and Ward, N. J. (**2004**). "Effects of naturalistic cell phone conversations on driving performance," J. Safety Res. **35**, 453–464.

Reddy, R., Welch, D., Ameratunga, S., and Thorne, P. (**2014**). "Development of the hearing protection assessment (HPA-2) questionnaire," Occup Med (Lond) **64**, 198–205.

Rennies, J., Warzybok, A., Brand, T., and Kollmeier, B. (**2014**). "Modeling the effects of a single reflection on binaural speech intelligibility," J. Acoust. Soc. Am. **135**, 1556–1567.

Samuel, A. G., and Kraljic, T. (**2009**). "Perceptual learning for speech," Atten Percept Psychophys **71**, 1207–1218.

Schwartz, B. L. (**2008**). "Working memory load differentially affects tip-of-the-tongue states and feeling-of-knowing judgments," Mem Cognit **36**, 9–19.

Smalt, C. J., Calamia, P. T., Dumas, A. P., Perricone, J. P., Patel, T., Bobrow, J., Collins, P. P., Markey, M. L., and Quatieri, T. F. (**2020**). "The effect of hearing-protection devices on auditory situational awareness and listening effort," Ear Hear **41**, 82–94.

Sommers, M. S., Tye-Murray, N., Barcroft, J., and Spehar, B. P. (**2015**). "The effects of meaning-based auditory training on behavioral measures of perceptual effort in individuals with impaired hearing," Semin Hear **36**, 263–272.

Spencer, N., Thompson, E. R., Wisniewski, M. G., Simpson, B. D., and Iyer, N. (**2016**). "Auditory training and subsequent generalization with speech and non-speech stimuli," J. Acoust. Soc. Am. **140**, 3269–3270.

Strand, J. F., Brown, V. A., Merchant, M. B., Brown, H. E., and Smith, J. (**2018**). "Measuring listening effort: Convergent validity, sensitivity, and links with cognitive and personality measures," J. Speech. Lang. Hear. Res. **61**, 1463–1486.

Strauss, D. J., and Francis, A. L. (**2017**). "Toward a taxonomic model of attention in effortful listening," Cogn Affect Behav Neurosci **17**, 809–825.

Thompson, E. R., Iyer, N., Simpson, B. D., Wakefield, G. H., Kieras, D. E., and Brungart, D. S. (**2015**). "Enhancing listener strategies using a payoff matrix in speech-on-speech masking experiments," J. Acoust. Soc. Am. **138**, 1297–1304.

Trabeau, M., Neitzel, R., Meischke, H., Daniell, W. E., and Seixas, N. S. (**2008**). "A comparison of 'Train-the-Trainer' and expert training modalities for hearing protection use in construction," Am. J. Ind. Med. **51**, 130–137.

Wisniewski, M. G. (**2017**). "Indices of effortful listening can be mined from existing electroencephalographic data," Ear Hear **38**, e69–e73.

Wisniewski, M. G., Radell, M. L., Church, B. A., and Mercado, E. III (**2017a**). "Benefits of fading in perceptual learning are driven by more than dimensional attention," PLoS One **12**, e0180959.

Wisniewski, M. G., Thompson, E. R., and Iyer, N. (**2017b**). "Theta- and alpha-power enhancements in the electroencephalogram as an auditory delayed match-to-sample task becomes impossibly difficult," Psychophysiology **54**, 1916–1928.

Wisniewski, M. G., Church, B. A., Mercado, E. III, Radell, M. L., and Zakrzewski, A. C. (**2019**). "Easy-to-hard effects in perceptual learning depend upon the degree to which initial trials are 'easy,'" Psychon Bull Rev **26**, 1889–1895.

Yeung, N., and Summerfield, C. (**2012**). "Metacognition in human decision-making: Confidence and error monitoring," Philos Trans R Soc Lond B Biol Sci **367**, 1310–1321.

Zekveld, A. A., Heslenfeld, D. J., Johnsrude, I. S., Versfeld, N. J., and Kramer, S. E. (**2014**). "The eye as a window to the listening brain: Neural correlates of pupil size as a measure of cognitive listening load," Neuroimage **101**, 76–86.