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STEM Degrees: 1 **STEM Participants:** 48

Major Goals: 1. Determine role of acoustic similarity on change detection and object encoding.
2. Determine role of timing parameters on change detection and object encoding.
3. Evaluate role of high-level factors in change detection.
4. Training to improve auditory memory.

Accomplishments: See uploaded document. In summary, four empirical papers have been published and several more are currently being prepared for submission. Four review papers have been published that discuss this research. Data collection is complete for all studies.

Training Opportunities: Professional development was provided for several post-doctoral, graduate, and undergraduate trainees. This included learning how to conduct research under the guidance of the PI and other trainees, presentation of work at conferences, and preparation of manuscripts for publication.

Results Dissemination: Research was reported at numerous conferences over the course of the project. Several empirical and review papers were published, and several more are being prepared for publication.

Honors and Awards: The PI was awarded the 2013 William Morris Excellence in Scholarship Award from the College of Liberal Arts at University of Nevada, Las Vegas.

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PARTICIPANTS:

Participant Type: PD/PI
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Person Months Worked: 2.00 **Funding Support:**
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Other Collaborators:

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Authors:
Keywords: change deafness, change detection, event-related potentials, auditory scene analysis

Abstract: Change deafness is the failure to notice changes in an auditory scene. In this study, we sought to determine if change deafness is a perceptual error, rather than a reflection of verbal memory limitations. We also examined how successful encoding of objects within a scene is related to successful detection of changes. Event-related potentials (ERPs) were recorded while listeners completed a change-detection and an object-encoding task with scenes composed of recognizable sounds or unrecognizable temporally scrambled versions of the recognizable sounds. More change deafness occurred for the unrecognizable, compared to recognizable sounds, indicating that change deafness is a perceptual error and not solely a product of verbal memory. ERPs from both the recognizable and unrecognizable scenes revealed an enhanced P3b (at PZ/1/2, POZ/3/4 from 350-750 ms) to detected changes, a marker that conscious change detection has occurred. Recognizable scenes resulted in an enhanced T400 (at T8/TP8,

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Authors: Joel S. Snyder, Mounya Elhilali
Keywords: auditory scene analysis, concurrent sound segregation, auditory stream segregation, informational masking, change deafness

Abstract: Studies of auditory scene analysis have traditionally relied on paradigms using artificial sounds—and conventional behavioral techniques—to elucidate how we perceptually segregate auditory objects or streams from each other. In the past few decades, however, there has been growing interest in uncovering the neural underpinnings of auditory segregation using human and animal neuroscience techniques, as well as computational modeling. This largely reflects the growth in the fields of cognitive neuroscience and computational neuroscience and has led to new theories of how the auditory system segregates sounds in complex arrays. The current review focuses on neural and computational studies of auditory scene perception published in the past few years. Following the progress that has been made in these studies, we describe 1) theoretical advances in our understanding of the most well-studied aspects of auditory scene perception, namely segregation of sequential patterns of sounds and concur

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Article Title: Effects of capacity limits, memory loss, and sound type in change deafness

Authors: Melissa K. Gregg, Vanessa C. Irsik, Joel S. Snyder

Keywords: Auditory memory, Change deafness, Processing capacity

Abstract: Change deafness, the inability to notice changes to auditory scenes, has the potential to provide insights about sound perception in busy situations typical of everyday life. We determined the extent to which change deafness to sounds is due to the capacity of processing multiple sounds and the loss of memory for sounds over time. We also determined whether these processing limitations work differently for varying types of sounds within a scene. Auditory scenes composed of naturalistic sounds, spectrally dynamic unrecognizable sounds, tones, and noise rhythms were presented in a change-detection task. On each trial, two scenes were present- ed that were same or different. We manipulated the number of sounds within each scene to measure memory capacity and the silent interval between scenes to measure memory loss. For all sounds, change detection was worse as scene size increased, demonstrating the importance of capacity limits. Change de- tection to the natural sounds did not...

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Statement of the problems studied

1. Determine role of acoustic similarity on change detection and object encoding.
2. Determine role of timing parameters on change detection and object encoding.
3. Evaluate role of high-level factors in change detection.
4. Training to improve auditory memory.

Summary of the most important results

General approach and accomplishments

In all experiments described below, the basic task is usually to listen to two, 1-second long scenes that are separated by a silent interval or presented immediately adjacent in time, and respond whether the two scenes are the same or different. Scene 1 and scene 2 are each comprised of four sounds. All studies contained both "same" and "different" trials. A "same" trial has identical sounds in both scenes, while a change during a "different" trial consists of a sound in scene 1 being replaced by a new sound in scene 2. In some experiments, an object-encoding task is added to each trial, in which a single sound is played and participants judge whether the sound was in at least one of the two scenes or not. In total, four empirical papers have been published and several more are currently being prepared for submission. Four review papers have been published that discuss this research. Data collection is complete for all studies.

Event-related potential study of change deafness

To address **Aim 3**, we completed a study to determine if change deafness is a perceptual error, rather than a reflection of verbal memory limitations (Gregg, Irsik, & Snyder, 2014). In this study, we also examined how successful encoding of objects within a scene is related to successful detection of changes. Event-related potentials (ERPs) were recorded while listeners completed the change-detection task, and participants also performed an object-encoding task, with scenes composed of four recognizable sounds or four unrecognizable temporally scrambled versions of the recognizable sounds.

More change deafness occurred for the unrecognizable scenes, compared to recognizable scenes, but participants were still able to detect changes in unrecognizable scenes some of the time, as suggested by d-prime values > 1 for both recognizable and unrecognizable scenes. This suggests that verbal and/or semantic information is helpful for encoding sounds, remembering sounds, and/or comparing successive scenes but that in the absence of such high-level information, it is still possible to detect changes using only low-level acoustic information. ERPs from both the recognizable and unrecognizable scenes revealed an enhanced P3b (at PZ/1/2, POZ/3/4 from 350-750 ms) to detected changes, a marker that conscious change detection has occurred, consistent with other recent ERP studies (Gregg & Snyder, 2012; Puschmann et al., 2013). Recognizable scenes resulted in an enhanced T400 (at T8/TP8, C6/CP6 from 315-660 ms) to detected changes, possibly indicating the recruitment of more established memory representations that is possible when verbal and semantic cues are available. Unrecognizable scenes elicited an enhanced P3a (at FCZ/1/2 from 280-600 ms) to detected changes, indicating enhanced orienting to acoustic change, consistent with a previous study that used non-meaningful sounds (Puschmann et al., 2013).

Performance on the object-encoding task revealed that change deafness was reduced, but not eliminated, when objects involved in the change (i.e., an object from the pre-change or post-change scene) were accurately encoded. Although poor object encoding does account for a portion of change deafness, other factors likely also contribute to the occurrence of change deafness.

Finally, this study also allowed us to address **Aim 1**, in a similar manner as our study that was published before the grant started (Gregg & Snyder, 2012). In particular, we found that change detection performance on unrecognizable sounds was better when the acoustic similarity between the four objects within both scenes was more widely distributed and when the change from Scene 1 to Scene 2 was between more acoustically different objects. However, we did not find these effects for recognizable sounds, unlike in our 2012 study.

Attention cueing and object-encoding during change detection

To address **Aim 3**, we completed a behavioral study to determine whether a cue toward an unchanging auditory object in scene 1 would impair change detection and whether a cue toward the to-be-changed object in scene 1 would improve change detection, compared to having no cue (Irsik, Vanden Bosch der Nederlanden, & Snyder, 2016). Previous research has shown that a cue toward the to-be-changed auditory object aids in change detection and may even eliminate change deafness (Eramudugolla, Irvine, McAnally, Martin, & Mattingley, 2005), but no studies have determined the effect of cueing to unchanging auditory objects. Participants in this study listened to two counter-balanced blocks: 1) with visual cues of the name of one of the sounds in the first scene and 2) with only the words "listen carefully" before scene 1. Participants' error was greater for "different" trials that cued attention to unchanging sounds in scene 1 (*invalid cue*) compared to both a cue to the to-be-changed sound in scene 1 (*valid cue*) and performance with no cue at all (*uncued*). Cueing appeared to benefit, but not eliminate, change deafness when compared to having no cue. These findings also suggest that invalid cues impaired change detection because attention was diverted from other, change-relevant objects, which resulted in a failure to encode any other elements of the scene.

While the results above imply that elements in the scene that are not cued are harder to encode or perhaps even fail to be encoded, this assertion was not tested directly. We assessed which objects the listener encoded during different cueing conditions and how identifying specific auditory objects affected their performance as we have done previously in an uncued setting (Gregg et al., 2014). The object-encoding sound presented could be 1) the changing sound from scene one, 2) the changing sound from scene two, 3) present in both scenes, or 4) present in neither scene. We found that when participants correctly identified change-relevant sounds (i.e., sounds that changed in either scene) they had less error on the detection task than when they failed to identify the change-relevant sounds during the uncued condition and for the cued condition under certain circumstances described in more detail below.

For the change detection data, we again found significantly higher error rates for invalid compared to valid cue conditions, but this study did not show the same decrease in change deafness for valid cues compared to no cue that was observed previously. When comparing the results of the current experiment to the previous directed attention experiment, error rates were significantly lower overall, but the order of presentation (i.e., either hearing the cued block first or the uncued block first) also significantly affected performance. Since the only difference between this paradigm and the one reported above was the presence of object encoding, these differences seem to be related to participants' abilities to individuate the sounds when they are presented in isolation during the object-encoding task. But the difference due to order is not simply an effect of task or sound familiarity because the second block does not result in better performance for each group; instead participants who did the cued block first had higher error overall. Our evidence suggests that when participants heard the uncued block first, they were able to orient to changing sounds, which resulted in fewer change detection errors. Yet, participants who heard the cued block first adopted the cueing strategy even during the uncued block, narrowing their attention and failing to detect changes at a greater rate than participants in the uncued block first. Participants' error on change detection trials when split by object-encoding performance also suggests that participants who began in the cued block focused attention more narrowly than those who began in the uncued block. Participants beginning in the cued block showed no difference in error rates between correctly and incorrectly identified change-relevant trials during the invalid cue condition, while participants beginning in the uncued block had significantly better change detection for correctly vs. incorrect change-relevant objects. Despite identifying change-relevant objects during invalid trials, participants that began in the cued block were unable to make use of their awareness of other objects within the scene. Together these results suggest that in circumstances in which participants are readily able to individuate sounds, cueing is an ineffective strategy but the natural scope and/or direction of attention resulted in better change detection performance.

Development of change deafness

We completed a study demonstrating the first evidence that, from 6 years of age, children exhibit change deafness (Vanden Bosch der Nederlanden, Snyder, & Hannon, 2016). Our main interest in using a standard change deafness paradigm was to address **Aim 1** and **Aim 3** during development. Specifically, although 6-year-olds clearly have knowledge of basic level categories, such as dogs, birds, girls, and boys, there is no evidence to suggest that children use this knowledge to make sense of complex sound scenes they encounter every day.

We assessed change detection through four conditions: across-category, within-category, short acoustic distance, and long acoustic distance. Category changes were matched for acoustic distance in a 2-dimensional Euclidian space of Harmonicity and Fundamental Frequency, while short distance changes were between 0-3 units and long distance changes were selected between 8-13 units. Within-category changes were two exemplars of a single basic level category (e.g., a change from the sound of a small dog barking to the sound of a big dog barking), while all other change types were across-category (e.g., a change from a small dog barking to the sound of a trumpet). We also assessed object encoding (**Aim 1**) to determine whether children could encode individual objects, to examine whether object encoding changed with age, and to examine whether attention to change-relevant objects (sounds unique to scene 1 or unique to scene 2) affected change deafness (**Aim 3**) compared to change-irrelevant objects (sounds present in both or in neither scene). Finally, we grouped all sounds during change detection and object encoding tasks into four superordinate categories of musical instruments, environmental sounds, animal vocalizations, and human voices. Using these four superordinate categories we were able to further address **Aim 3** by assessing how high-level factors such as the social relevance of the sound category affected both change detection and object encoding.

Change deafness decreased with age, but we found no developmental differences for the use of acoustic similarity over semantic information as we had predicted. Listeners of all ages had more change deafness on within-category than across-category trials and more change deafness for short compared to long acoustic changes. The small, but significant effect for acoustic change magnitude is inconsistent with a previous study looking only at adult listeners (Gregg & Samuel, 2009), which find a robust effect for acoustic change magnitude. The use of our object-encoding task may have also inadvertently biased listeners to attend to the object-level of analysis during our change deafness task.

Object-encoding results revealed that children have more trouble encoding individual objects than adults. The pattern of object-encoding performance was similar for each age group, however, with change-relevant objects encoded more poorly than change-irrelevant objects (both or neither types). When listeners were able to encode change-relevant sounds, their change deafness performance decreased compared to when they were not able to encode the sound and compared to when they encoded change-irrelevant objects in the scene. Thus, like adults in previous work from our lab, when children attend to the changing sounds in either scene, change deafness is significantly reduced.

Finally, we found novel evidence that children and adults preferentially attend to socially relevant sounds in complex acoustic scenes. For all listeners, the human voice was more readily detected and better encoded than all other stimulus classes.

Change deafness for specific sound categories

To further address **Aim 3** we completed a study examining whether adults detect changes for all human sounds, or whether it is specific to communicative human sounds (Vanden Bosch der Nederlanden, Zaragoza, Rubio, Clarkson, & Snyder, in preparation). Previous work from our lab has shown that already from age 6, listeners are better at detecting when a human voice changes compared to other real-world sounds in complex acoustic scenes (Vanden Bosch der Nederlanden et al., 2016). To extend and replicate this finding, we further examined what factors led to this advantage for detecting the human voice in complex scenes.

We found that participants detected changes to human communicative sounds better than human non-communicative sounds and several other sound categories. Even though our communicative sounds were all vocally generated, about half contained speech sounds, which makes it possible that the benefit was driven primarily by speech sounds. Some of our non-communicative sounds also contained vocally-generated human sounds, which may have artificially lowered rates of change deafness for non-communicative sounds.

To further understand the beneficial effect of communicative sounds, we split our communicative and non-communicative categories further into speech vs. non-speech communicative sounds and vocal vs. non-vocal non-communicative sounds. For sound replacing in Scene 2 there was a main effect for human sound type, but no interaction. Planned comparisons between human sound types indicated that there was less change deafness for communicative speech compared to all other sounds. Non-vocal non-communicative sounds exhibited the largest amount of change deafness even compared to non-speech and non-communicative vocal tract sounds. There was no difference between communicative non-speech and vocal non-communicative sounds.

When the same analyses were carried out for the sound dropping out of scene 1, there was again a main effect of human sound type and musicianship, but also an interaction. Speech, non-speech, and vocal non-communicative sounds were all low in change detection rates and did not differ from each other, but all sounds were detected better than non-vocal non-communicative sounds. Simple effects split by musicianship revealed the same pattern as the omnibus, with the only difference arising from less change deafness for musicians on non-communicative vocal tract sounds than speech sounds. Although it is unclear why this pattern is present, it may be related to the exploratory analyses described above, with two non-communicative sounds (chewing and sniffing) having wide and flat frequency spectra, which may have been better detected by musicians than non-musicians. In sum, it appears as though any vocal sound is detected better than a non-vocal sound when it is dropped from scene 1, but, for the changing sound in scene 2, speech is detected better than other vocal sounds, regardless of their communicative status, in addition to a benefit compared to non-vocal sounds. These findings suggest that speech sounds themselves are responsible for the low rates of change deafness for communicative sounds, but the vocal nature of communicative and non-communicative sounds also contributes to better change detection.

Individual differences in change deafness

Much of our previous work has focused on group differences in rates of change deafness as a function of specific experimental conditions. However, there is often a large amount of variability in participant's responses. As such, we used the just discussed data set to systematically examine whether factors like musical training, musical sophistication, executive function, auditory working memory, or general intelligence could predict error on different trials in a standard change deafness paradigm (Vanden Bosch der Nederlanden, Zaragoza, Rubio, Clarkson, & Snyder, in preparation). The participants included 30 non-musicians and 30 musicians in order to address **Aim 3**. Executive functioning (EF) was examined through Berg's Card Sort (similar to Wisconsin Card Sort) and the Color-Word Stroop. Together these EF tasks assess the listeners' selective attention, inhibition, and task switching abilities. Auditory memory was assessed using the forward and backward digit span subtests of the Wechsler Adult Intelligence Scale (WAIS). Individual's speech-in-noise abilities were also assessed using a multiple signal-to-noise ratio version of the R-SPIN. The R-SPIN presents intelligible sentences within multi-talker babble and the listener's task is to repeat back only the final word of the sentence. Each word is presented twice, once with a high probability carrier sentence (e.g., "The dog chewed the bone") and another time with a low probability carrier sentence (e.g., "We discussed the bone"). This allows us to examine each individual's ability to use context in order to disambiguate the final word, especially at low SNRs. To characterize musical training, we used both self-report (number of years playing/practicing music, age of music lesson onset) and a behavioral assessment called the profile of Music Perception Skills (PROMS; Law & Zentner, 2012). The brief version of the PROMS includes four subtests designed to assess each listener's ability to perceive differences in rhythm, tuning, tempo, and melody. Finally, we included the Wechsler Abbreviated Scale of Intelligence (WASI – II) 2-subtest (Vocabulary and Matrix Reasoning) Full Scale IQ. In a single, 2-hour session, participants performed all of the above listed tasks in addition to a 240-item (50% different/change trials) change deafness task.

Overall, musicians performed better than non-musicians on our change deafness task, with less error on different trials and no difference between error on same trials. Thus, we provide the first evidence, to our knowledge, that musical training is related to better detection of changes in everyday complex scenes. Further, musicians showed better performance for words with high probability carrier sentences, but no such difference was found for words with low probability carrier sentences. Musicians also had significantly higher full scale IQ than non-musicians, but there was no difference for verbal or matrix reasoning subtests alone. This finding is, again, consistent with the previous literature on musical training and IQ, but the difference is smaller than previous studies have reported. Finally, as anticipated, musicians outperformed non-musicians on all subtests of the PROMS. All other comparisons did not reach statistical significance.

In order to examine which factors influenced change detection directly, we used EF, R-SPIN, IQ, PROMS, musical training (age of onset, duration of training) and Digit Span tasks to predict error on different trials in a linear regression. On the first step of the model, we entered IQ and age, and on the second step of the model all other factors were entered in a stepwise fashion. Age and IQ accounted for 6 percent of the variance and on the second step the only additional significant predictor was duration of musical training, adjusting the R^2 of the model to 19.6%. On the third step, R-SPIN performance on the hardest SNR (-1, signal was 1 dB quieter than babble), also resulted in a significant change in R^2, now allowing the model to account for 28.9% of the variance in error on different trials. Taken together, musical training plays the largest role in predicting less error for detecting acoustic changes. Of course, it is important to acknowledge that we were only able to account for about 30% of the variance in this population, which suggests that there are many other factors untested here that contribute to change deafness. We are currently in the process of analyzing and writing up these findings for submission.

Effect of energy drink on attention allocation during change detection

In order to explore other factors that may influence attention in auditory processing (**Aim 3**), the effect of energy drink consumption compared to a placebo drink was examined using the same cueing paradigm (Dadis, Irsik, & Snyder, in preparation). Participants either consumed an 8 oz serving of a caffeinated energy drink with glucose or a non-caffeinated placebo drink (without glucose), after which they completed two counter-balanced blocks: 1) with visual cues of the name of one of the sounds in the first scene and 2) with only the words “please proceed to the next trial” before scene 1. As was found in our previous experiment, a cue to the to-be-changed object (*valid cue*) benefited change detection, and a cue to an unchanging sound (*invalid cue*) impeded change detection. Next, while error on all "different" trials (*i.e., invalid, valid, and uncued*) was reduced for those who consumed an energy drink, this difference was not significant. Due to the transient nature of sounds, listeners have limited exposure to auditory information. This may drive a larger degree of vigilance and attention as compared to visual attention where exposure to stationary objects is not limited. Therefore, the size of the effect that caffeine and glucose may have on auditory attention may be limited.

Biasing attention toward whole object vs. low-level acoustic details

In this study--which we do not plan to publish--participants provided responses in two experiments, one without the secondary object-encoding task and one with the object-encoding task. In Experiment 1, without object-encoding, participants used both object-level and acoustic detail to detect changes. This is evident by taking the difference between error on within- and across-category trials as well as the difference in error on acoustically similar than dissimilar trials. There is no difference between object-level category usage and acoustic similarity. In Experiment 2, the acoustic similarity difference score is at zero, meaning that there was no difference in error on acoustically similar vs. dissimilar changes. In contrast, there was significantly more error on within-category compared to across-category trials, resulting in a large difference score for object-level category knowledge. Thus for experiment 2, listeners were significantly more biased toward using object-level category knowledge than acoustic detail. This is in line with some of our recently published work in change deafness that shows a secondary task (object-encoding) can lead listeners to adopt different attentional strategies during a change detection task (Irsik et al., 2016). It is important to note, however, that even though we were successful in biasing attention toward the object level in Experiment 2, there was no difference in overall error on different trials comparing the studies directly.

Effects of inter-scene interval

We completed a set of experiments, which addresses **Aim 2** (Gregg, Irsik, & Snyder, 2017). In this study, we varied the time interval between Scenes 1 and 2. This manipulation provided us with basic information about how long the memory for Scene 1 can be sustained for useful comparison with Scene 2. We also varied the number of objects present (i.e., scene size) to see if this variable interacts with the time interval. This addresses an important theoretical issue about the nature of the memory for scenes, in particular whether it is capacity limited (cf. Demany et al., 2008). We evaluated memory for simple sounds (pure tones and noise bursts) and complex sounds (the recognizable and unrecognizable environmental sounds used in the experiment described above) using the change-detection task. For all sounds, performance was worse as scene size increased. Performance for complex sounds was not much affected by the interval between scenes, except for very long intervals (e.g., 6000 msec), whereas for simple sounds memory appeared to decay more readily. Our results suggest that auditory memory for complex sounds is surprisingly enduring and does not decay or get interfered with over time. While memory capacity for complex sounds is limited, once information is encoded in memory, it is quite robust.

Effect of temporal onset delays and temporal order on change detection performance

This study was designed to test **Aim 2** using two manipulations: delaying the onset of each auditory object within a scene and scrambling the temporal order of the auditory objects within a scene (Vitela & Snyder, in preparation). The onset delay and temporal order were manipulated as a first step in determining whether listeners detect changes by comparing the global spectral-temporal properties of the scenes or rely on detecting the individual sounds within the scene. If listeners rely on object encoding, then scrambling the temporal order should not affect their performance. However, if listeners rely on global properties (like the overall amplitude envelope or rhythmic properties of the scene), then scrambling the temporal order should affect their performance, making the task more difficult. Twenty-six listeners were run, assigned to either the Scrambled Temporal Order group or the Not Scrambled Temporal Order group. The task and stimuli for both were the same as that described previously in the "General approach", but the scenes included the two key manipulations. In the Not Scrambled Temporal Order, participants heard scenes with onset delays of 50, 200, and 400ms. For example, for the 50ms onset delay, the start of each auditory object within the scene began 50ms after the onset of the previous sound. The temporal order was maintained. For the Scrambled Temporal Order, the same onset delays were used, but the temporal order was scrambled. That is, no sound in scene 2 occurred in the same temporal position as it had in scene 1. For the Scrambled Temporal Order condition, a significant effect of onset delay was found between the 50ms and 200ms onset delays. Sensitivity to change was better in the 50ms condition. This suggests that listeners rely on a comparison of the global properties of scenes, as the manipulation of temporal order had a very small effect at 50ms and so the temporal structure was mostly maintained from scene 1 to scene 2. Further, the degree to which the temporal structure changed between scene pairs was correlated with listeners' different responses. This provides further support for listeners' reliance on the temporal structure for detecting changes.

Training to improve change detection

We have completed two experiments designed to address **Aim 4**. In the first, we examined: 1) whether listeners can learn to improve their change detection ability, 2) whether the presence of training versus testing results in improvement, and 3) how learning unfolds after training (Irsik & Snyder, submitted). All participants completed a series of change detection trials during a pre-test, a training activity, and an immediate post-test. Training involved participation in one of four activities: 1) Detailed Feedback Group: completed change detection trials and received detailed feedback on their performance. Detailed feedback informed the listener on the correctness of their response, after which the individual to-be-changed noise stream from scene 1 was presented, which was followed by a final replay of the current trial (i.e., scene 1 and scene 2) before moving forward to a new trial. 2) No Feedback, Long ITI Group:

completed the same number of change detection trials but received no feedback on performance. Trials were spaced to occur at the same time as the trials for the Detailed Feedback Group, which resulted in a long inter-trial-interval (ITI). 3) No Feedback, Short ITI Group: completed the same number of change detection trials and received no feedback on their performance. Each trial began immediately after a response was recorded, which resulted in a short ITI. 4) Control Group: watched a documentary for the same time it took the Detailed Feedback Group and the No Feedback, Long ITI Group to complete a training activity (approximately 45 minutes). In order to address the time course of learning after training, participants returned for a second post-test 12 hours later.

Those who received detailed feedback during training improved the most across test sessions, and showed a 14-point reduction in percent error from pre-test to post-test two. The No Feedback, Long ITI Group showed a 7-point reduction in error, while the No Feedback, Short ITI Group and Control Group performed similarly and showed a 9-point reduction in error across test sessions. Percent error on "same" trials (i.e., false alarms) was relatively stable across test session. These data indicate that participants can significantly improve change detection ability through training and receiving feedback (i.e., Detailed Feedback Group improvement), although the significant improvement of the remaining groups demonstrates that a benefit of testing can also be achieved. In summary, change deafness was reduced, but not eliminated, as a result of training or testing.

We have finished an additional training study for **Aim 4** (Irsik & Snyder, in preparation-b). The primary goal of this experiment was to address whether training induced change detection improvement reflects an overall improved ability to detect changes, or whether learning is specific to the sounds exposed to during training (rote learning). To address this, we examined whether practicing change detection with different objects improves change detection performance relative to a group that trains on the same objects and a control group that does not receive any training. If the group that trains with different objects improves more than the group that trains on the same objects, this shows that there are benefits of practicing with different objects (generalization). However, if they do not improve more than the other group, inducing rote learning would be a better strategy for improving change detection and practice should be focused on the sounds with which the task will be performed.

Forty-five listeners were recruited for the experiment, which consisted of a small series of tests over a three-day period. On Day 1, each listener completed a pre-test. On Day 2, those not assigned to the control group practiced change detection during a training session and received detailed feedback after each response. Detailed feedback indicated whether a response was correct or incorrect and identified the trial type (e.g., Correct! This was a same trial). Next, the target sound from Scene 1 plays in isolation after which both Scene 1 and Scene 2 are re-presented before the next trial begins. Depending on random group assignment, listeners either practiced with old familiar sounds heard during the pretest (n=15) or with a group of novel sounds (n=15). The control group (n=15) did not participate in any task on this day. On Day 3, all listeners completed a post-test which contains sounds heard in the pretest and also a new group of novel sounds. Finally, EEG was recorded during the pre-test and post-test to observe the presence of any neural changes that occur as a function of training, and to address possible differences due to learning through generalization or rote learning.

First, we compared error rates between the pre-test and post-test[1] to observe overall training effects. While error on different trials was substantially reduced at post-test, same trial error significantly *increased*. Consequently, error rates were converted to *d'* and c to better characterize overall change sensitivity and response bias, respectively. Examination of *d'* revealed no significant improvement for any of the three groups at post-test for new sounds or old sounds; however, inspection of individual scores indicated variability in pretest *d'* and learning between participants. Examining c indicated a substantial alteration in participant bias from responding 'no, there was no change' to 'yes, there was a change'; however, a significant interaction indicated the change in response bias was primarily found in the two training groups and not the control group. Since there were no differences observed between training groups, and no overall change at all in control participant scores, the remaining analyses will contain pooled data from the trained groups only.

Analyzing the trained participant's EEG data revealed several modulations that index processes occurring during accurate change detection. For example, pre-test ERPs revealed a fronto-central sustained negative potential (FN) during scene 1 (latency 370-1000 ms), and a P3 response during scene 2 (latency 400-1000 ms) that were enhanced for detected relative to not-detected different trials. The latter finding is consistent with our prior work on change deafness (Gregg & Snyder, 2012; Gregg, Irsik, & Snyder, 2014) and represents what we believe to be a neural correlate of successful change detection; however, the FN response is novel. We believe it may be an indicator of enhanced attention or feature mapping during scene 1 that leads to successful change detection. This possibility will be revisited below following comparisons between pretest and post-test ERPs. There was an overall reduction in amplitude for post-test ERPs for different trials. In scene 1, N2 (latency 250-300) and FN responses during old and new sounds are significantly reduced, while the reduction in P3 was not quite significant. Making a similar comparison for same trial ERPs also revealed a significant reduction in N2 and FN components from scene 1, once again similarly for old and new sounds.

Given that ERP amplitude at pretest appeared to coincide with change detection accuracy, we examined the change in ERP amplitude as a possible predictor of changes in *d'* from pre-test to post-test using multiple linear regression. C was also added as a predictor variable since it was found to change following training during behavioral analyses. Overall, amplitude changes in the same FN component were successful in predicting d*'* alongside changes in c; however, only changes in the different FN component during old sounds were similarly successful in predicting *d'*. Changes in P3 amplitude for old sounds neared significance as a predictor, but was entirely unsuccessful for new sounds. Taken together, participants were more successful at improving during the change detection task by retaining a 'no' bias and a larger and more negative same FN response.

Despite its presence during accurate change detection, P3 was not useful in predicting detection improvement following training. One explanation may be that amplitude measures for P3 may not well-suited to capture the underlying source configuration changes that occur following learning. Another explanation may be that P3 is best used as a detection index for unfamiliar sounds. For example, P3 amplitude was highly positively correlated with *d'* at pretest, which indicated that larger amplitude was associated with better performance. At post-test, P3 amplitude was no longer correlated with *d'* for old sounds, but there was a positive correlation

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[1] Post-test performance for old and new sounds was pooled to minimize the number of statistical comparisons for this initial inspection. Subsequent analyses examine post-test changes relative to pretest separately for old and new sounds.

with P3 amplitude and *d'* for new sounds. Since listeners were able to detect changes with the same accuracy for novel and familiar sounds at post-test, these findings may suggest that there are multiple context-dependent change detection mechanisms available for use.

To summarize, our results show that participants can reduce change detection error using training, however, the simultaneous increase in false alarm rate calls into question whether participants truly increased their overall detection sensitivity. This discrepancy between our current and previous training study may be due to the relative difficulty of detecting changes with different sound types. More specifically, the current study used complex recognizable sounds while the previous study used simple noise rhythms. Training to improve change detection with complex sounds may take additional days of training to observe reduced change detection error along with low and stable false alarm rates. Unfortunately, the participant's variable response to training makes our original objective difficult to resolve. The current data do not show any benefit for training with one stimuli set over another; however, this may change if a training session is more effective than what was observed here. We were able to identify at least two ERPs which index essential change detection processes. The FN response not only indexed accurate change detection at pretest, but its change following training was also a significant predictor of participant learning. On the other hand, the P3 response appears well-suited to index change detection processes with unfamiliar sounds, however, alternative measures appear needed to index change detection with familiar sounds.

Based on this study, we suggest that training to improve change detection improves perceptual abilities more generally, and does not involve improvement due to object memorization or rote learning—a finding in contrast to what has been found in the visual domain with change blindness (Gaspar, Neider, Simons, McCarley, & Kramer, 2013). The absence of attention and change-detection related ERPs after training further suggests that our training session appears to have positively altered sensory processing to allow for more accurate and less effortful processing of auditory information. Finally, while neural changes specific to rote learning and generalization are unclear, we are utilizing other tools to more thoroughly investigate our physiological data.

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