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Change Deafness: A Comprehensive Examinations

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CHANGE DEAFNESS: A COMPREHENSIVE EXAMINATION

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Abstract

Environmental changes are a vital source of information which can drive advantageous behavioral responses. For example, detecting visual changes can be critical when driving a vehicle or when simply walking down a busy street. Auditory perception is an essential complement to vision as it can allow awareness of changes in and out of sight. While subjective perception would suggest that our sensory representation of the world is complete, research on change deafness indicates that quite often the opposite is true. Healthy listeners often miss salient, suprathreshold auditory changes. Three separate manuscripts will be presented, each of which aims to advance the current understanding of change deafness using a different approach. The first manuscript examined how focused attention modulates auditory scene perception, and found that attention to change-relevant objects is crucial for successful change detection, and that encouraging broad attention to multiple objects is the best way to reduce change deafness. The second manuscript examined whether auditory memory limitations are a significant cause of change deafness, and found that change detection is generally limited by capacity, but that auditory memory long lasting for sounds with naturalistic acoustic structures. Finally, the third manuscript determines whether change deafness can be reduced by training, and found that auditory change detection can be enhanced relatively rapidly, although the training regimen type can determine whether improvement occurs immediately (fast learning) or if learning continues to develop hour after training ceased (slow learning). Together, the data generated from these experiments has led to a better understanding of what causes change detection error and whether it can be reduced.

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Chapter 1: General Introduction

Forming a perceptual representation of the objects we encounter is an essential and nearly continuous process due to the dynamic nature of most settings. Visual information represents a significant part of our basic perceptual experience and is crucial for many everyday tasks (e.g., driving, walking, reading, etc.). On the other hand, audition is valued for supporting verbal communication but is quite often considered secondary to vision in terms of importance. Yet, auditory information can provide a unique sense of awareness which extends beyond certain limitations of vision. For example, reduced visibility can occur in complex environments when visual objects spatially overlap, leading to partial or complete masking of some objects. While there are scene analysis mechanisms in place to perceptually segregate and represent overlapping visual objects (cf. visual scene analysis; Marr, 1982), this process is limited to objects that are at least partially visible.

On the other hand, auditory perception can be used to detect an object or change which is completely out of sight. For example, switching lanes when driving can lead to an accident if a neighboring vehicle is not visible (e.g., due to a blind spot, driver error, etc.). Honking a car horn can help prevent a collision by warning another driver that they are unsafely switching lanes. Of course, auditory information is also useful for detecting objects or changes in less serious scenarios. Recognizing a familiar voice can help with finding a friend in a large crowd. Hearing an object hit the floor can also warn an individual when they have dropped a personal item. Importantly, detecting a change in any of these scenarios would be useful since it can motivate an advantageous behavioral response, such as reversing an unsafe action while driving or retrieving a dropped personal item.

Ideally, a percept should accurately reflect the physical world it characterizes; however, the inherent complexity of most environments complicates the transformations that lead to perception. Auditory perception is particularly complex in environments that contain ongoing and overlapping sounds. For example, if multiple sounds enter the ear simultaneously, the individual waveforms sum together and stimulate auditory receptors as a single waveform (Yost, 2006). Presumably, listeners can perceptually segregate sounds using a process called *auditory scene analysis* (ASA; Bregman, 1990), during which listeners detect feature regularities to segregate and integrate auditory features into distinct auditory objects or streams. The terms 'auditory object' and 'auditory stream' are conceptually similar since they both refer to acoustic information generated by a single source, although 'stream' is primarily used to characterize continuous sound patterns which unfold over several seconds (Shinn-Cunningham, 2008).

During ASA, listeners organize auditory information using a combination of two distinct procedures, sequential segregation (Snyder & Alain, 2007) and concurrent segregation (Alain, 2007). Sequential segregation is used to separate two or more ongoing sound patterns that do not overlap in time (e.g., A-b-A-b…→ A-A…and b-b…), whereas concurrent segregation is used when two or more sounds simultaneously overlap (e.g., AbAbAbAb→ A-A-A-A…and b-b-b-b …). During sequential segregation, sound patterns are segregated on the basis of ongoing differences in fundamental frequency (f_0), rhythm, and loudness (Cusack & Roberts, 2004; Hartmann & Johnson, 1991). During concurrent segregation, simultaneous sounds can be separated either by listening for amplitude fluctuation differences between competing sounds (e.g., dip listening; Gustafsson & Arlinger 1994; Vélez & Bee, 2011), or by listening for differences in the harmonic structure between sounds (e.g., f_0, timbre, harmonicity; Alain, Schuler, & McDonald, 2002). Depending on the listening environment, one or both segregation methods may be used. For example, having a conversation in a noisy restaurant would require segregation and integration of the features belonging to the target voice and background noise (i.e., sequential segregation), as well as concurrent segregation at any point where the target voice was simultaneous with background voices or noise.

While ASA undoubtedly provides a strategy for organizing complex listening environments, the average listener's capability to accurately represent the environment may be overestimated. Research on change deafness has revealed that listeners quite often miss suprathreshold changes (Dickerson & Gaston, 2014; Snyder & Gregg, 2011). Notably, the term 'change deafness' does not refer to clinical deafness or a type of hearing loss. On the contrary, the term change deafness refers to a high level of auditory change detection error that is observed in *healthy listeners*. The term is also meant to relate to the well-known visual phenomenon change blindness (Simons & Levin, 1998); the research of which has served as a useful starting point for designing and motivating change deafness studies. For example, an auditory adaptation of the one-shot paradigm from the visual domain (e.g., Levin & Simons, 1997) has been the most common method for measuring change deafness. During a typical trial, participants hear two consecutive groups of sounds (i.e., auditory scenes) and are asked to make a same/different judgment. The two groups of sounds are either identical (same trial), or one of the objects in the second group has changed (different trial). For example, listeners may be asked to detect when an object in the second group of sounds has been added (e.g., $[X_1X_2X_3]$ $[X_1X_2X_3X_4]$; Constantino et al., 2012), deleted (e.g., $[X_1X_2X_3]$ $[X_1X_2]$; Eramudugolla et al., 2005) has replaced another object (e.g., $[X_1X_2X_3]$ $[X_1X_2X_4]$; Gregg & Samuel, 2008), or has switched spatial locations with another object (Backer & Alain, 2012).

The sounds used in a particular study can also vary. As an example, some studies have used simple static sounds in place of auditory scenes, such as complex tones or chords (e.g., Demany et al., 2008; Demany et al., 2010). Others have used auditory scenes composed of simple noise rhythms (i.e., band-pass filtered noise rhythms, each with a different frequency range and rhythm; cf. Puschmann et al., 2013). One limitation of using static sounds or very simple auditory stimuli is that they do not contain the rich spectro-temporal structure of the sounds that most realistic listening environments contain. Therefore, the vast majority of change deafness studies have used scenes composed of spectro-temporally complex recognizable sounds (e.g., music; environmental sounds; human speech; Eramudugolla et al., 2005; Gregg & Samuel, 2008; Gregg & Samuel, 2009; Pavani & Turatto, 2008; but see Gregg, Irsik, & Snyder, 2014). Overall, change detection error rates are high across studies and range from 30-55%. Therefore, change deafness appears to reflect a general limitation of the auditory system that is not restricted to a particular stimulus category.

The acoustic features of an auditory scene are an important determinant of successful change detection. For example, listeners struggle to detect a change when a new sound is highly similar to the other sounds in an auditory scene (e.g., $f_{0,}$ harmonicity) (Gregg & Samuel, 2008), likely due to difficulty with segregation. Better performance occurs when a new sound differs from the group in at least one acoustic dimension, and difficulty decreases as sound similarly also decreases. Aside from acoustics, participants can also use semantic information to guide change detection. In fact, semantic content tends to outweigh feature-level information as a cue. In Gregg and Samuel (2009), participants had more difficulty detecting when a sound changed to a semantically similar object (e.g., from small dog bark to large dog bark), compared to when a sound changed to an object of a different semantic category (e.g., from dog bark to trumpet), even when the size of the acoustic change was equated between conditions. Therefore, while the acoustic content of a scene can facilitate change detection, participants depend more on semantic cues than acoustics to detect changes.

While there has been a fair amount of research on change deafness, there are still many unanswered questions regarding underlying causes. In contrast, change blindness has been examined extensively and is considered fairly well understood. Research from the visual domain is often a useful starting point in auditory research, as drawing comparisons between modalities can generate theoretical perspectives which characterize sensory processing in general. Accordingly, the background and method from three separate manuscripts will be discussed, each of which examines different influential factors from vision research in the context of change deafness. For example, evidence from change blindness research has suggested that attention is critical for detecting visual changes since objects outside the focus of attention are not well-encoded (Rensink et al., 1997). The effect of attention has also been previously examined in two separate change deafness studies; however, the conclusions of both studies are limited since they only examined how change detection was impacted when attention was directed *towards* a change, but not *away* from a change. Therefore, the first manuscript systematically examines the effect of attention on auditory change detection by using multiple types of attentional cues (cf. Rensink et al., 1997), and determines how attention differentially alters the representation of various objects in an auditory scene.

In addition, visual change detection is also impacted by a limited-capacity and limited-duration visual short-term memory (Rensink, 2002). More specifically, there are limitations to the number of visual objects that can be accurately held in memory, and visual objects can only be held in memory for a limited time before the memory trace begins to fade. Therefore, change blindness can occur if the visual scenes have a large number of objects, and if the delay interval between visual scenes is too long. There have been some attempts to determine whether similar auditory memory limitations contribute to change deafness; however, drawing conclusions between studies is difficult since the method used in each study has been inconsistent. Therefore, the second manuscript comprehensively examines whether change deafness is caused by a limited-capacity and limited-duration auditory memory by using multiple stimulus types, a wide range of delay intervals, and by manipulating the number of auditory objects in each auditory scene.

Thus far, research on both change blindness and change deafness has focused on identifying root causes, but has very rarely assessed whether training or practice could be used to eliminate either phenomenon. In fact, there has only been one study that has used training to reduce change blindness, and there have been zero studies that have examined training and change deafness. Determining whether training can reduce change deafness is important from a practical perspective, as change detection is a useful skill for everyday tasks and especially critical for certain professions (e.g., military and law enforcement personnel). Therefore, the third and final manuscript determines whether change deafness can be eliminated by training. Together, these findings will generate a better understanding of the phenomenon of change deafness, and provide data that suggests several key differences between vision and audition.

Chapter 2: Broad Attention to Multiple Individual Objects May Facilitate Change Detection with Complex Auditory Scenes[1]

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Abstract

Attention and other processing constraints limit the perception of objects in complex scenes, which has been studied extensively in the visual sense. We used a change deafness paradigm to examine how attention to particular objects helps and hurts the ability to notice changes within complex auditory scenes. In a counterbalanced design, we examined how cueing attention to particular objects affected performance in an auditory change-detection task through the use of valid or invalid cues and trials without cues (Experiment 1). We further examined how successful encoding predicted change-detection performance using an object-encoding task and we addressed whether performing the object-encoding task along with the change-detection task affected performance overall (Experiment 2). Participants had more error for invalid compared to valid and uncued trials, but this effect was reduced in Experiment 2 compared to Experiment 1. When the object-encoding task was present, listeners who completed the uncued condition first had less overall error than those who completed the cued condition first. All participants showed less change deafness when they successfully encoded change-relevant compared to irrelevant objects during valid and uncued trials. However, only participants who completed the uncued

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[1] Copyright © 2016 by the American Psychological Association. Reproduced with permission. Irsik, V.C., Vanden Bosch der Nederlanden, C.B., & Snyder, J.S. (2016). Broad attention to multiple objects may facilitate change detection with complex auditory scenes. *Journal of Experimental Psychology: Human Perception & Performance, 42*(11), 1806-1817.

condition first also showed this effect during invalid cue trials, suggesting a broader scope of attention. These findings provide converging evidence that attention to change-relevant objects is crucial for successful detection of acoustic changes and that encouraging broad attention to multiple objects is the best way to reduce change deafness.

Introduction

Everyday listening situations can contain multiple co-occurring sounds, often with overlapping spectral and temporal information. Through a process called *auditory scene analysis* (Bregman, 1990), listeners perceptually segregate and fuse together acoustic information to form auditory objects. However, forming auditory objects can be difficult when the sound of one object physically masks another object (energetic masking), when there are a large number of sounds in a scene, or when the sounds in a scene are complex (informational masking; Durlach et al., 2003; Gregg & Samuel, 2008). Selective attention can act as a “spotlight” to help filter out less informative objects and this may be key to minimizing listeners’ perceptual load when processing complex auditory scenes (Best, Gallun, Ihlefeld, & Shinn-Cunningham, 2006). Attention also plays an important role in both the object formation process and in consciously perceiving formed objects (Alain & Arnott, 2000; Cohen, Cavanagh, Chun, Nakayama, 2012; Shinn-Cunningham, 2008; Snyder, Gregg, Weintraub, & Alain, 2012, but see Sussman, Horvath, Winkler, & Orr, 2007; Scholes, Palmer, & Sumner, 2015). Thus, attention is an integral part of the way we encode and process auditory objects.

Attention is not a unitary phenomenon, however, as listeners may allocate their attention to many possible levels of analysis. That is, a listener could adopt a local scope of attention toward individual features of an object or toward one object in a scene (e.g., Gregg & Samuel, 2009). Alternatively, listeners could adopt a more global attentional scope toward a whole scene consisting of multiple objects (e.g., Ahissar, Nahum, Nelken, & Hochstein, 2009) or toward only the global acoustic properties of an auditory scene, without attention to individual objects themselves (e.g., Greene & Oliva, 2009). The scope and locus of one’s attention has implications for how much and what kind of information a listener can encode. Historically, selective attention’s effect on auditory processing was investigated using dichotic listening tasks in which listeners heard different speech streams, one in each ear, and were asked to ignore one stream and focus on the other (Cherry, 1953; Pashler, 1997). Task-irrelevant information was generally filtered out and ignored, leaving the listener with access to only task-relevant information from the attended stream. For example, when listeners were told to allocate their attention to one sentence by repeating one of two competing speech streams aloud (i.e., shadowing), listeners failed to notice when the language of the unattended speaker changed from English to German (Cherry, 1953). Furthermore, listeners have missed changes to features that are task-irrelevant even within an attended stream, such that shadowing a speech stream or listening to and answering questions during a phone interview led listeners to miss a change to the vocal identity of the attended speaker (Vitevitch, 2003; Fenn et al., 2011).

However, details from ignored elements are not always lost to the listener. Participants inadvertently began to shadow a speech stream in their unattended ear when the attended message switched ears with the ignored stream (Treisman, 1960). This typically occurred without the listener’s awareness that a switch ever occurred, suggesting that listeners monitored information from both ears simultaneously. Similarly, even when participants failed to notice that the identity of a voice changed during a naturalistic telephone conversation, those same participants could reliably recognize both voices compared to a voice they never heard (Fenn et al., 2011). Therefore, task-relevant details may be readily encoded and accessible, while details from ignored sources are at times processed and can trickle into perception. However, it is unclear how well these findings describe auditory processing under more natural conditions. Dichotic listening tasks, such as those described above, may amplify the effect of selective attention on auditory scene processing by providing two easily distinguishable sound sources and by requiring participants to allocate all of their attention to the difficult task of shadowing an unfamiliar speech stream or to answering complex autobiographical questions. A task that encourages listeners to monitor multiple auditory objects in a complex auditory scene would allow us to examine whether unattended objects are completely ignored or whether other elements in a scene are encoded but simply weighed less heavily than an attended object.

Change deafness (Dickerson & Gatson, 2014; Snyder & Gregg, 2011; Snyder, Gregg, Weintraub, & Alain, 2012), the auditory analogue to change blindness (Simons, 2000; Simons & Rensink, 2005), has been useful for investigating the role of attention when processing relatively naturalistic auditory scenes. Using the *one-shot paradigm*, in which participants hear two consecutive auditory scenes, researchers found that cueing a listener's attention to the to-be-changed object greatly enhanced their ability to detect changes between auditory scenes. When attention was directed to the changing sound using a visual cue prior to the start of a trial (e.g., the word "cello" to cue a cello sound), change deafness was largely eliminated (Eramudugolla et al., 2005). However, when an object was replaced with a different auditory object in scene 2 instead of simply being omitted, change deafness was merely reduced compared to no cue, but not eliminated. Similarly, a cue that highlighted the spatial location of the to-be-changed sound after the first auditory scene reduced change deafness compared to performance with no cue (Backer & Alain, 2012). However, in both of these studies, cues were 100% valid, meaning that the cue always directed attention toward a changing sound during a "different" trial. The use of 100% valid cues does not allow for a systematic examination of how selective attention affects the encoding of unattended sounds within the scene. Without cues that direct the listener's attention to unchanging sounds within each scene, it is not possible to address whether focused attention on a change-irrelevant sound interferes with the encoding of the changing sounds between each scene.

In the visual domain, early work on selective attention and luminance detection found a processing cost when participants' attention was directed away from the location of the change with an invalid cue (e.g., Posner, Snyder, & Davidson, 1980). This indicates that there are limits as to what an individual can encode when attention is focused in a particular direction, and might also suggest that a broad attentional scope may be more advantageous than a narrow focus. There is one study to our knowledge that has compared change detection with valid cues, invalid cues, and no attentional cues using a more complex change blindness paradigm. In this study, participants were better at detecting changes with a valid cue compared to no cue, and performance was worse for invalid cues than valid cues, but this latter effect did not reach statistical significance (Rensink, O'Regan, & Clark, 1997). Rensink and colleagues proposed that attended objects were maintained in a durable memory store, while unattended objects were free to be replaced or overwritten in memory by new objects, which prevents observers from detecting changes to the unattended objects. Thus, when attention is not directed toward changing objects within a scene, a changing object may fail to be encoded and compared with the replacing object.

If change detection in the auditory domain is similar to the visual domain, then invalid cues directing participants' attention to unchanging objects on "different" trials may result in significantly worse error relative to a valid cue or no cue. However, there is some evidence that auditory change detection is different than visual change detection. For instance, in one study a cue was more beneficial in the visual domain than the auditory domain during change detection tasks using simple visual and auditory objects (Demany et al., 2010). In particular, participants were more sensitive to changes in a circular dot array with a valid spatial cue compared to no cue (difference of 2.2 *d'* units), whereas participants had a much smaller increase in sensitivity for valid compared to uncued frequency changes within a group of pure tones (difference of .74 *d'* units; Demany et al., 2010). Thus, it is possible that attention in auditory scenes is in general more broadly distributed than in vision, such that, even though a valid cue may decrease change detection errors somewhat, an invalid cue may not result in more change deafness than having no cue. However, it is also possible that the individual frequencies were not well segregated in this study because they were static and had common onsets and offsets (Dannenbring & Bregman, 1978; Elhilali, Ma, Micheyl, Oxenham, Shamma, 2009). Thus, using more complex natural stimuli with time-varying structure might reveal stronger effects of selective attention in auditory scenes.

Whether or not auditory attention is more broadly focused than visual attention overall, participants' attention can be biased toward a more global or local level of analysis. In vision, different attentional strategies can reduce the well-known phenomenon of an attentional blink, where detecting one visual target in a rapid serial visual presentation (RSVP) task causes the second target to go unnoticed when it occurs within 500 ms of the first target (Raymond, Shapiro, & Arnell, 1992). When participants were told to report all letters in the RSVP task there was no memory interference for subsequently encoded letters, but a large attentional blink occurred when participants were told only to report the target letter or color, suggesting that the slow re-allocation of narrowly focused attention led to an attentional blink (Nieuwenstein & Potter, 2006). There is also evidence that individual preferences toward global or local structural levels can predict the extent of an attentional blink. Specifically, participants with a global attentional bias have a smaller attentional blink than those who demonstrate a local attentional bias on a separate global-local figural processing task (Dale & Arnell, 2010).

Although there is evidence for a global processing bias in both vision and audition (Navon, 1977; Justus & List, 2005; Ouimet, Foster, & Hyde, 2012), there is no evidence to our knowledge that in the auditory domain global or local attentional strategies can be induced to alter change detection performance within complex auditory scenes. In the visual modality, participants exhibited less change detection error at global and local levels when spatial cues were provided to the relevant level of analysis (Robertson, Egly, Lamb, & Kerth, 1993; Robertson, 1996). Further, participants carried over the cued level of analysis (i.e., global or local) from a previous block to subsequent blocks containing no cues (Robertson et al., 1993) and showed level-specific priming even when the stimulus changed location, color, polarity, or contrast (Robertson, 1996). In a change deafness task, a cue may alter the level of analysis listeners use to detect changes. Specifically, a cue to a single object within a scene may lead to a more local level of analysis, while providing no cue may allow participants to attend more globally to all objects within a scene. As such, if keeping a broad scope of attention is advantageous for change detection, then a valid cue may not reduce change deafness beyond having no cue.

In the present study, we aimed to address whether listeners could detect changes between complex scenes composed of everyday sounds in the same manner as Posner, Snyder, and Davidson (1980), when participants' attention was directed toward the to-be-changed sound in the first scene (valid cue), toward a sound that did not change during either scene (invalid cue), or when their attention was not directed (no cue) during a separate block. Overall, valid cues are anticipated to facilitate change detection compared to invalid cues. Additionally, valid cues are expected to reduce memory load and reduce change deafness compared to no cue because task difficulty may be significantly reduced. Finally, we predict that focused attention toward a cued sound will reduce the scope of encoded material, which will significantly increase change deafness during trials with an invalid cue. However, if auditory attention is naturally broadly focused, then having an invalid cue may not negatively impact change detection performance.

Experiment 1

Method

Participants. Eighteen listeners with no reported hearing loss, neurological, or psychiatric disorders participated in Experiment 1 (14 females and 4 males; mean age= 19.06, SD= 1.12). All listeners were UNLV undergraduates naïve to the predictions of the study. Course credit was assigned as compensation. Data from one additional participant was excluded from the current analysis because a computer error occurred, resulting in the loss of data. All participants provided informed consent according to a protocol approved by the UNLV Institutional Review Board.

Apparatus. Sounds were presented over Sennheiser HD 280 Pro headphones at a comfortable listening volume (approximately 65 dB SPL). A custom Presentation script was used to deliver stimuli and record participants' keyboard responses on a PC running Windows 7.

Stimuli. Auditory scenes were composed from the 15 environmental sounds listed in Table 1, each lasting 1000 milliseconds (ms). These sounds have been used previously to examine change deafness (Gregg and Samuel, 2008; Gregg & Snyder, 2012). All sounds were digitized to a sampling rate of 44.1 kHz, matched for mean amplitude, filtered for noise, and had 10 ms ramps added to sound onsets and offsets to avoid abrupt transitions. We used a custom

MATLAB script to randomly select and group the sounds into 400 scenes, each containing 4 auditory objects with simultaneous onsets.

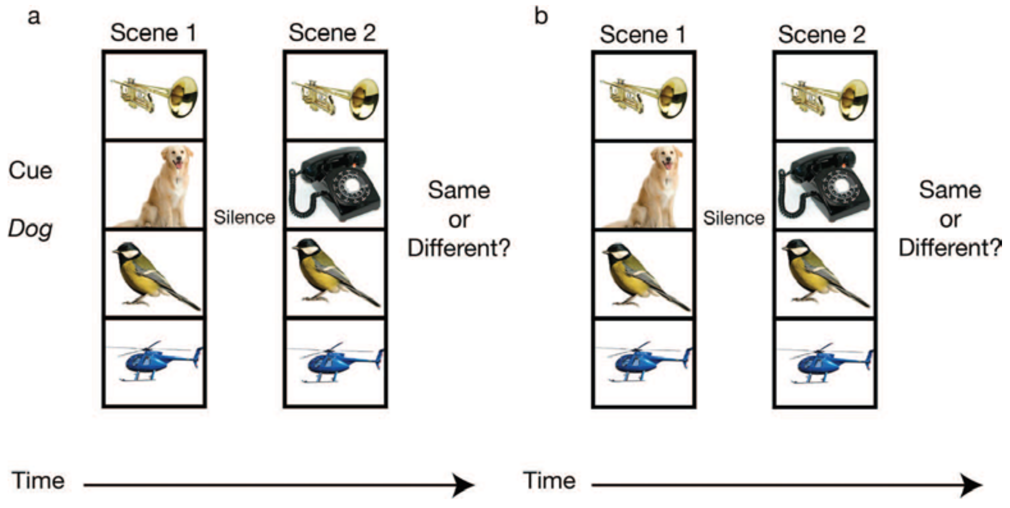
Table 1. Environmental sounds used in Experiment 1 and Experiment 2.

Sounds	
Bird chirping	Bacon sizzling
Bubbles	Female speaking
Cello	Helicopter
Chicken	Male speaking
Clapping	Party horn
Cricket	Phone ringing
Clock ticking	Piano
Trumpet	

Procedure. During each trial, participants heard two auditory scenes (i.e., scene 1 followed by scene 2), separated by a 350 ms silent interval. The sounds in scene 2 were either identical to those in scene 1 (same trial), or contained three of the same sounds from scene 1 and one new sound (different trial). The task was to report by button press whether scene 1 and scene 2 were the “Same” or “Different”. Equal proportions of same and different trials were used.

We examined the effect of attention by either directing attention to an auditory object within scene 1 (cued condition) or by providing no cue to guide the locus of attention within scene 1 (uncued condition). Each condition was assessed separately in two blocks of 200 trials, presented in a counterbalanced order (i.e., half of participants did the cued condition first). Breaks were provided halfway through each block. In the cued condition, each trial was preceded by a visual cue (a word) corresponding to one of the 15 environmental sounds (see Figure 1a for schematic). Participants were instructed to pay attention to the visually cued sound during the upcoming trial and advised that the cue could be helpful for the change detection task. Visual cues correctly identified the changed sound from scene 1 75% of the time (valid cue), or identified a sound that would not change on 25% of the trials (invalid cue). An unequal proportion (75/25) of valid and invalid cue trials was used in order to bias the participant to trust the usefulness of the cue. During the uncued condition, participants completed change detection trials without a preceding visual cue (See Figure 1b for schematic). Out of the 200 trials in the cued condition there were 100 same trials and 100 different trials. Unless otherwise specified, all planned comparisons were performed using the Least Significant Differences Correction.

Figure 1. Example of the a) cued and b) uncued change detection conditions.

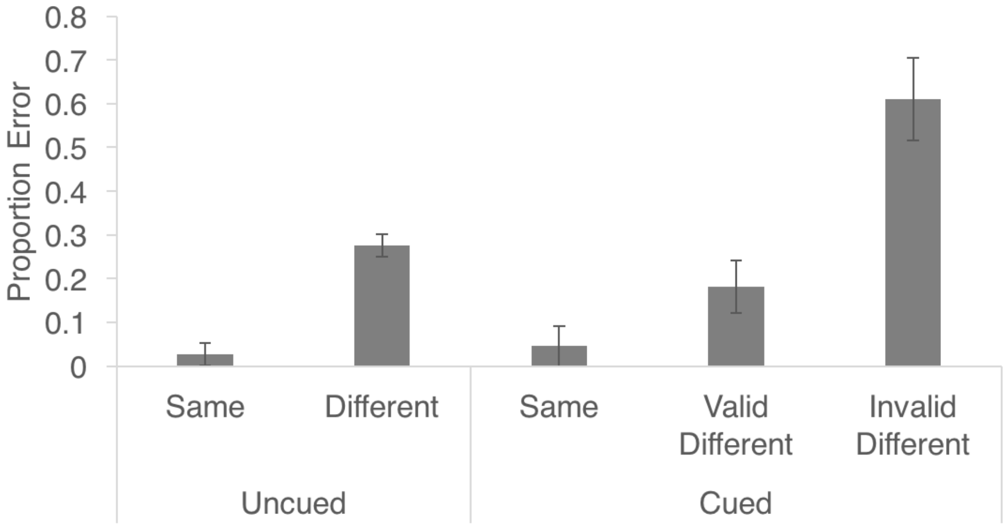


Results

For the uncued condition, participants' mean error was submitted to a mixed-design Analysis of Variance (ANOVA) with condition order (cued first, uncued first) as a between-subjects factor and trial type (same, different) as a within-subjects factor. Participants showed evidence of change deafness, which is defined as significantly greater error on different trials (i.e., missed changes) than same trials. This was evidenced by a significant main effect of trial type, *F*(1, 16) = 86.13, $p < .001$, $\eta^2_p = .84$ (different trial error = 28%, same trial error = 3%; see Figure 2). No significant interaction between trial type and condition order was found ($p = .85$), indicating that the order of presentation for cued and uncued trial blocks had no effect on performance.

For the cued condition, a second mixed-design ANOVA was carried out with condition order (cued first, uncued first) as a between-subjects factor and trial type (same, valid cue different, invalid cue different) as a within-subjects factor. A significant main effect of trial type was found, *F*(2, 32) = 42.89, $p < .001$, $\eta^2_p = .73$. Planned comparisons showed significantly greater error on both valid (18%) and invalid cue different trials (61%) compared to same trials (5%; *p's* < .001), demonstrating significant change deafness for cued trials. Additionally, valid and invalid cue trials were significantly different from each other ($p < .001$). Finally, no effect of condition order ($p = .81$) or significant trial type by condition order interaction were found ($p = .94$).

Figure 2. Proportion of error on same and different trials for the uncued and cued conditions in Experiment 1. Error bars represent within-subjects confidence intervals (Cousineau, 2005).



To investigate our main question concerning the effect of directed attention on change deafness, performance between all trial types (uncued, valid cue, invalid cue) were analyzed for different trials only. We found a significant main effect of different trial type, $F(2, 32) = 24.92$, $p < .001$, $\eta^2_p = .61$. Planned comparisons showed significantly greater error on uncued different trials (28%) compared to valid cue different trials (18%; $p < .001$), which indicated that a cue towards a to-be-changed sound facilitated change detection, or reduced change deafness. This result suggests that maintaining a broad scope of attention is not beneficial compared to when a valid cue can reduce the amount of information that needs to be encoded within a scene. Again, significantly greater error was found during invalid cue trials (61%) compared to valid cue trials (18%; $p < .001$) and error was also greater on invalid cue trials compared to uncued different trials (28%; $p < .001$), which demonstrates the deleterious effect of misdirected attention on change deafness.

Discussion

When attention was directed to unchanging sounds via an invalid cue, participants had significantly greater change deafness compared to when they had either no cue or a valid cue to the changing sound in scene 1. This pattern of results is consistent with the visual change detection literature (Posner et al.,1980; Rensink et al., 1997), which suggests that unattended objects are not fully encoded, whereas attended objects are encoded and stored in a more durable format that allows participants to compare objects between scene 1 and scene 2. It is also interesting to note that attending to an invalid cue compared to no cue results in a much larger cost to change detection performance (33% performance cost) than the benefit that is evident from a valid cue compared to no cue (9% performance benefit). Our results suggest that when participants directed their attention to a particular object, it reduced their ability to encode other objects within the scene, which resulted in a significant cost in their ability to detect changes to objects that were not cued. However, we did not directly assess how much of the scene listeners encoded. To directly address this question, the next experiment examined how well participants were able to encode other objects in the scene during invalid cue and uncued trials and whether encoding change-relevant objects could predict change detection performance in different cueing conditions.

Experiment 2

Experiment 2 used an object-encoding task (Mitroff, Simons, & Levin, 2004; Gregg & Samuel, 2008, 2009; Gregg, Irsik, & Snyder, 2014) to examine whether participants were unable to detect changes after an invalid cue or with no cue because of a failure to encode change-relevant auditory objects (i.e., the to-be-changed sound from Scene 1 or the changed sound from Scene 2). By asking participants an object-encoding question on each change detection trial, we could also examine the impact of attention toward specific types of auditory objects during the related change-detection task. A previous study has shown that correctly encoding change-relevant objects was associated with significantly less error than incorrectly encoding these objects (Gregg et al., 2014). This suggests that encoding specific objects rather than processing the scene as an undifferentiated whole is important for successful change detection.

Our object-encoding task also has the potential to bias participants to attend toward individual auditory objects, which may result in a different pattern of performance in Experiment 2 compared to Experiment 1. An object level of analysis may lead listeners to form strong representations of individual objects, and it may also require listeners to maintain multiple individual objects in memory during the change-detection task so that they can respond accurately about the presence or absence of a sound. In this case, listeners may have less error for invalid cue trials compared to Experiment 1 because they may be motivated to attend to all auditory objects instead of just the cued object. Further, if encoding individual objects is important for successful change detection, as opposed to attending to global acoustic features, then overall error could further decrease change deafness compared to Experiment 1.

The aim of the current study was to (a) replicate the results from Experiment 1, (b) determine whether the object-encoding task would alter the effect of a valid cue compared to an invalid cue or no cue, (c) examine whether objects that were not the target of a cue during the directed attention condition were encoded in memory, and (d) investigate whether accurately identifying change-relevant objects would lead to less change deafness regardless of the presence of a cue or type of cue. Given the results from Experiment 1, we anticipated that during the directed attention condition participants would have high error on the object encoding task for objects that were not cued. Further, we anticipated that correctly identifying change-relevant objects would result in less change-detection error than incorrectly identifying them for both uncued and valid cue trials.

Method

Participants. Twenty-nine participants were recruited in the same manner as Experiment 1. Participants had no reported hearing loss, neurological, or psychiatric disorders (20 females and 9 males; mean age= 19.76, SD= 2.23). Six additional participants were excluded from the study because of health history precluding them from participation (n=2; seizures, tinnitus), because they were too old (n=1), because of technical malfunction (n=1), or because they were statistical outliers for same trial performance (n=2). Outlier qualification was determined by use of a non-recursive elimination procedure (Van Selst & Jolicoeur, 1994). All listeners were undergraduates naïve to the predictions of the study. Course credit was assigned as compensation. All participants provided informed consent before participating and the University's Institutional Review Board approved all materials. Thus, analyses were carried out on 29 participants, 14 participants hearing the uncued condition first and 15 participants hearing the cued condition first.

Apparatus. Apparatus was identical to Experiment 1.

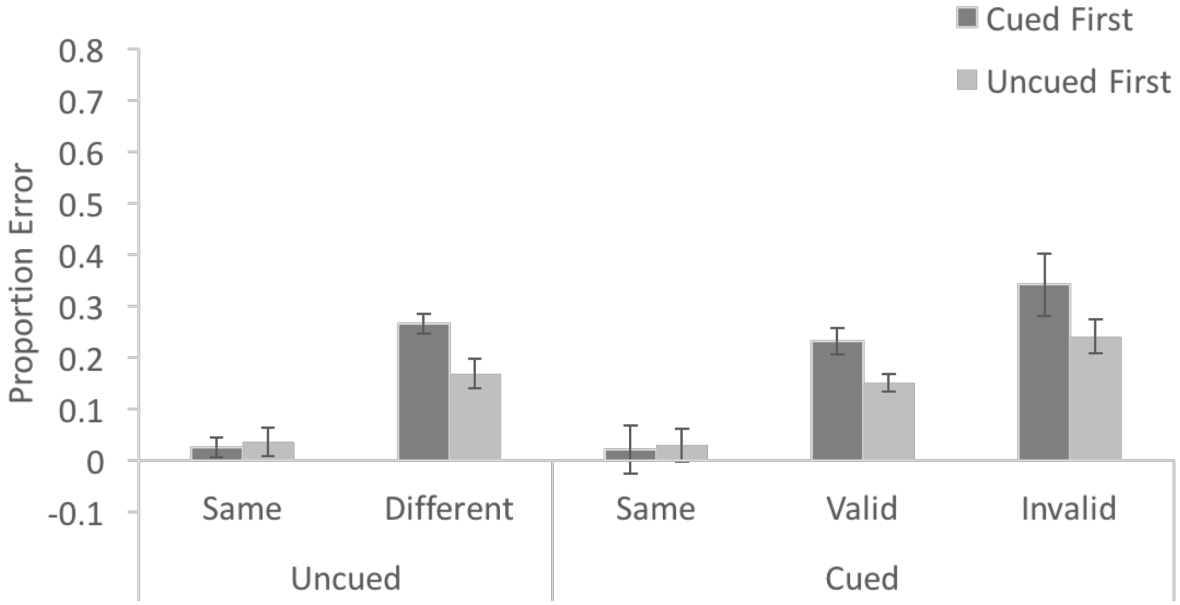
Stimuli. Stimuli were identical to Experiment 1, but sounds (See Table 1) were also presented in isolation for the object-encoding questions.

Procedure. The procedure was identical to Experiment 1, except for the addition of a second task to determine how well specific sound types were encoded within each scene. On each trial, the object-encoding (OE) task began 500 ms after participants provided a response for the change detection task. Participants heard a single sound lasting 1000 ms and were asked "Did you hear this sound during the last change detection task?". Participants responded by pressing a button for either “yes” or “no” to indicate whether they heard the sound in either of the last two change detection task scenes. OE stimuli represented four possible types of sounds depending on their presence in the change detection task. Different trials had an OE sound that was present in both scenes (both), neither scene (neither), only scene 1 (scene 1), or only scene 2 (scene 2), while only two types were possible for same trials (i.e., both and neither OE types because sounds do not change from scene 1 to scene 2). This resulted in 50 of each OE question type (i.e., both, neither) for both uncued and cued same trials and 25 of each OE type for uncued different trials. For cued different trials, there were also 25 of each OE type, with 19 of each occurring during valid cue trials, and 6 of each type occurring during invalid cue trials. It should be noted that valid and invalid cues direct attention towards different OE sound types. Since a valid cue directs attention towards the to-be-changed sound in scene 1, a scene 1 OE question on valid cue trials probes a listener's memory for the cued sound. Therefore, error during a scene 1 OE question on a valid cue trial would indicate a failure to encode the cued sound despite having attention directed towards it. In contrast, an invalid cue directs attention towards a sound present in both scene 1 and scene 2. As such, error during a scene 1 OE question during an invalid cue trial would indicate a failure to encode the scene 1 sound when attention was directed away from it.

Results

Change-detection performance. Mean error on the change detection task was again used to examine the presence of change deafness during cued and uncued conditions separately and for assessing the effect of different cue types (valid, invalid, no cue) on change deafness. For the uncued condition, participants again exhibited change deafness, $F(1, 27) = 118.88$, $p < .001$, $\eta^2_p = .82$, with greater error on different (22%) compared to same trials (3%). In contrast to Experiment 1, a significant effect of condition order was found, $F(1, 27) = 7.08$, $p = .013$, $\eta^2_p = .21$, with greater error overall for participants who heard the cued condition first compared to those who heard the uncued condition first (see Figure 3). Further, the interaction between trial type and condition order was significant, $F(1, 27) = 10.15$, $p = .004$, $\eta^2_p = .27$. This revealed that there was no difference in performance as a function of condition order on same trials ($p = .36$), but there was greater error on different trials for participants who heard the cued condition first compared to those who heard the uncued condition first (cued first: 27%, uncued first: 17%; $p = .004$; See Figure 3). Therefore, in contrast to Experiment 1, participants who completed the cued condition first had worse performance on different trials than those who completed the uncued condition first.

Figure 3. For Experiment 2, the proportion of error is shown for cued and uncued trials, split by condition order. Error bars represent within-subjects confidence intervals.



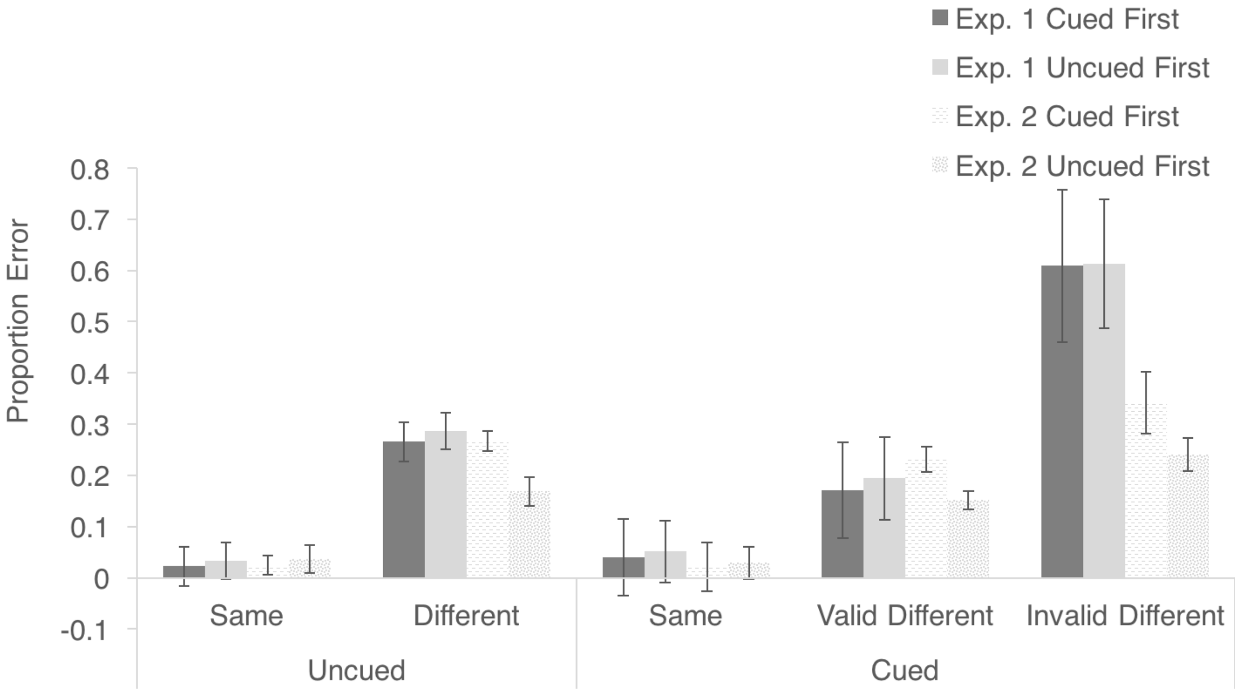
For the cued condition, both types of different trials (valid and invalid cue trials) resulted in significantly more error than same trials, $F(2, 54) = 60.64$, $p < .001$, $\eta^2_p = .69$, and planned comparisons also revealed greater error on invalid cue compared to valid cue different trials ($p < .001$). The effect for condition order, $F(1, 27) = 3.13$, $p = .088$, $\eta^2_p = .10$, and the interaction between trial type and condition order, $F(2, 54) = 2.83$, $p = .093$, $\eta^2_p = .10$, were not statistically significant, although these results follow the same pattern of performance as in the uncued condition. Thus, change deafness was also observed during cued trials, however it was reduced for valid compared to invalid trials overall.

In order to assess the benefit of a valid cue and the harmful effect of an invalid cue compared to no cue, we compared error rates for different trials in both the cued and uncued conditions (uncued, valid cue, invalid cue). We observed a main effect of different trial type, $F(2, 54)= 11.97$, $p < .001$, $\eta^2_p = .31$. Planned comparisons indicated that, in contrast to

Experiment 1 (see Figure 4 for a comparison), there was only a marginal difference between uncued (22%) and valid cue trials (19%; $p = .067$), but invalid cue trials (29%) resulted in significantly greater error than both a valid cue ($p < .001$) and uncued trials ($p = .006$; see Figure 3). A significant effect of condition order was found, $F(1, 27) = 5.67$, $p = .025$, $\eta^2_p = .17$, with significantly greater error for participants who heard the cued condition first overall compared to those who heard the uncued condition first (29% vs. 19% error, respectively). This effect did not differ as a function of trial type, as indicated by a non-significant interaction between trial type and condition order ($p = .808$). The main effect of order across different trials from both conditions indicates that participants did not simply improve performance over time or become more fatigued as the testing session continued. Instead, participants who heard the cued condition first had worse performance for both conditions compared to participants who heard the uncued condition first. As highlighted in Experiment 1, there is a greater cost of an invalid cue compared to no cue (7%) than there is a benefit for a valid cue compared to no cue (3%), although the effect of these cues on performance is markedly reduced in Experiment 2 compared to Experiment 1 (cost of invalid cue: 33%; benefit of valid cue: 9%).

The present experiment finds a similar pattern of results of as Experiment 1, but a valid cue did not lead to as large of a reduction in change deafness compared to having no cue. Further, even though an invalid cue continued to significantly impede change detection, the cost of an invalid cue was markedly reduced in the current experiment. The central difference between experiments was the addition of the object-encoding task in Experiment 2. The presence of this secondary task may have changed the attentional strategy used during change detection, given that listeners knew they would be asked to report the presence of individual objects.

Figure 4. Comparison of Experiment 1 and Experiment 2 across conditions by order. Less error was observed in Experiment 2 during uncued and invalid trials overall, but a reduction in error for uncued and valid cue trials was particular to those who heard the uncued condition first during the experiment. Error bars represent within-subjects confidence intervals.

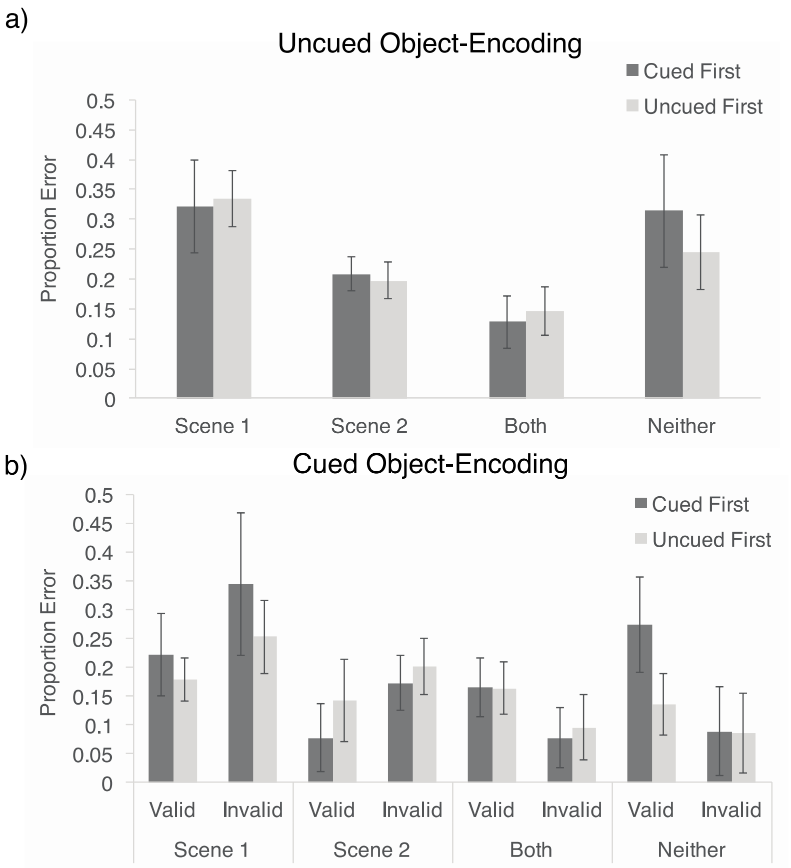


To explore this possibility, we directly compared performance on all different trials between Experiments 1 and 2 to determine what led to these observed performance differences (e.g., Is error in Experiment 2 higher on valid cue trials, lower on uncued trials, or both?). Error was greater overall for Experiment 1 compared to Experiment 2, $F(1, 43) = 13.47$, $p < .001$, $\eta^2_p = .24$. An interaction between experiment and different trial type, $F(1, 86)= 18.96$, $p < .001$, $\eta^2_p = .31$, led us to run three separate ANOVAs to examine the difference between experiments for each different trial type including condition order and experiment as factors. A significant main effect of experiment was found for uncued trials, $F(1, 43) = 4.64$, $p = .037$, $\eta^2_p = .10$, and invalid cue trials, $F(1, 43) = 20.50$, $p < .001$, $\eta^2_p = .32$, with greater error for participants in Experiment 1 compared to Experiment 2. An interaction between experiment and condition order was also observed for uncued trials, *F*(1, 43) = 4.78, p =.034, η^2_p = .10, but not for valid cue trials, *F*(1, 43) = 3.25, p = .078, η^2_p = .07, or invalid trials (p = .46; see Figure 4). Thus, less change deafness was observed for uncued trials when participants did the uncued condition first during Experiment 2, but no such difference was observed during Experiment 1 (see Figure 4).

These results suggest that the secondary task changed listeners' attentional strategy so that they could encode and maintain multiple objects in memory for the object-encoding task. This shift in attention toward individual objects benefited performance during uncued trials and, to an even greater extent, during invalid cue trials. A smaller but additional benefit was also observed for those who completed the uncued condition first. It seems that the efficacy of listeners' adopted strategy in Experiment 2 depended on whether they heard the cued or uncued condition first, with those that heard the cued condition first having a narrower, more local focus than those who listened to the uncued condition first. Importantly, though, the data do not provide evidence for an attentional set in which global properties of the acoustic scene are attended without attention to individual objects (cf. Greene & Oliva, 2009).

Object-encoding performance. To address the third aim of Experiment 2, we examined how well participants encoded individual objects when attention was directed toward the changing sound or an unchanging sound and when attention was not directed. As neither OE questions represent a different type of error (i.e., false alarms) than all other OE types (i.e., misses), these trials were analyzed separately from other OE types. Participants' mean error for the OE task in the uncued condition was submitted to a mixed-design ANOVA with OE question type (scene 1, scene 2, both, and neither) as a within-subjects factor and condition order (cued first, uncued first) as a between-subjects factor. A main effect of OE type was observed, *F*(3, 81) = 12.04, p < .001, η^2_p = . 31 (see Figure 5a). Planned comparisons indicated that all OE types were significantly different from each other at $p < .001$. No interaction or main effect for order was observed (*ps* _ .74, see Figure 5a). There was no main effect for neither OE trials ($p< .204$) and participants had 28% error overall for these trials. Thus, object encoding during the uncued condition was better when the object was present in both scenes and when the object was present in Scene 2, which is consistent with a recency effect.

Figure 5. Proportion OE error for each OE type during a) uncued trials and b) cued trials, both split by condition order. Error bars represent within-subjects confidence intervals.



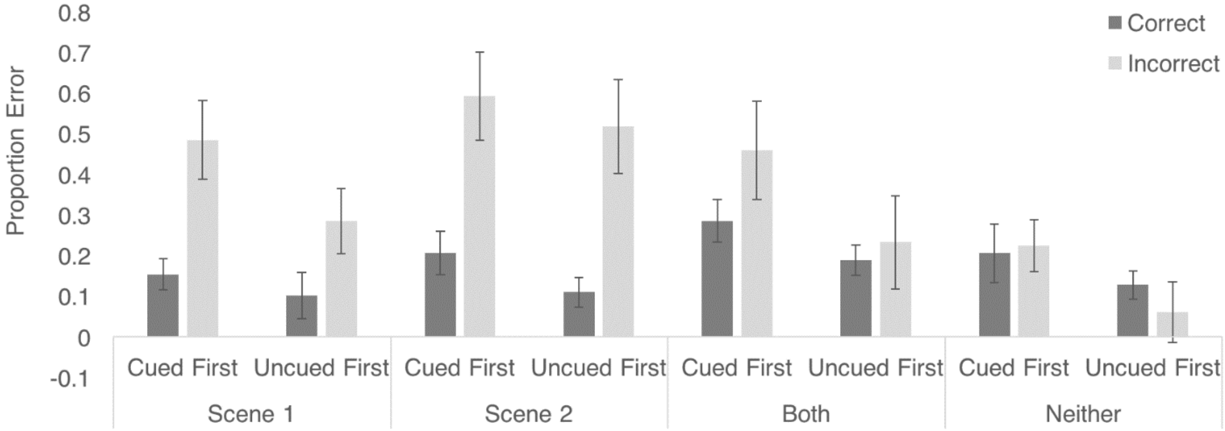
For the cued condition, participants' mean error on the OE task was submitted to a mixed-design ANOVA with OE question type (scene 1, scene 2, and both) and cue type (valid, invalid) as within-subjects factors and condition order (cued first, uncued first) as a between-subjects factor. After finding a main effect of OE type, $F(3, 81) = 6.31$, $p = .002$, $\eta^2_p = .19$, planned comparisons indicated that encoding was worse for scene 1 compared to scene 2 (*p* = .003), both (*p* < .001), and neither OE types (*p* = .018). Unlike the uncued condition, error for identifying objects present in both scenes was not different from scene 2 (*p* = .192; see Figure 5b). There was no main effect of cue type, *F*(1, 27) =1.33, *p* = .259, η^2_p = .05, but there was a statistically significant interaction between OE type and cue type, *F*(2, 54) = 9.68, *p*< .001, η^2_p=.26. To investigate the interaction, we performed separate ANOVAs for each OE type including condition order and cue type.

For these analyses, it is important to again highlight that the type of cue (valid or invalid) directed participants' attention either toward the scene 1 OE type (i.e., the to-be-changed sound from scene 1) on valid trials or toward a both OE type (i.e., a sound present in both scenes) on invalid trials. Not surprisingly, for scene 1 OE types, there was more error for invalid (30%) than valid (20%) cue trials, *F*(1, 27) = 7.01, *p* = .013, η^2_p = .21. Similarly, for both OE trials, there was less error for invalid cue trials (9%), when attention was directed toward an object that was present in both scenes, compared to valid cue trials (16%), *F*(1, 27) = 9.94, *p* = .004, η^2_p = .27. These results indicate that listeners were better at encoding individual objects when they were cued toward them, while objects that were not the target of a cue were not well encoded. For scene 2 OE types, participants had more error for valid (19%) compared to invalid (11%) cue trials, *F*(1, 27) = 6.43, *p*< .017, η^2_p = .19, which suggests that when participants were cued to the to-be-changed sound from scene 1, the replacing sound in scene 2 was harder to encode than when an invalid cue directed them toward an object present in both scenes.

The cost of a narrow focus on the cued sound is further evident on neither OE trials, where participants had more error for valid cue (21%) compared to invalid cue (9%) trials, *F*(1, 27)= 25.57, *p*< .001, η^2_p = .49. However, during neither OE trials, participants who heard the uncued condition first demonstrated less interference from a valid cue (i.e., less error) than those who heard the cued condition first (see Figure 5b), $F(1, 27) = 8.34$, $p < .008$, $\eta^2_p = .24$, which is consistent with a broader scope of attention. Together these results highlight that when attention is directed toward a specific sound, other sounds in the scene are not well encoded. However, the encoding benefit for an invalid cue during scene 2 and neither OE trial types—two instances in which the OE question probed a sound that was not the target of any cue type—suggests that directing a listeners' attention alone does not always reduce the listeners' ability to encode sounds that were not cued. Instead, the scope of encoded material depends on the type of sound toward which attention was directed (i.e., the to-be-changed sound from scene 1 or a sound present in both scenes).

Change-detection performance grouped by object-encoding performance. Finally, we investigated whether correctly encoding objects in our OE task was related to change deafness and whether directing a participant's attention altered how correctly encoding change-relevant or change-irrelevant objects affected change deafness. We examined mean percent error for different trials split by whether the probed OE sound was correctly or incorrectly identified, assessing uncued and cued trials separately. Again, neither trials were analyzed separately from other OE types. For uncued trials, mean change-detection error was assessed with condition order (cued first, uncued first) as a between-subjects factor and OE accuracy (correct, incorrect) and OE question type (scene 1, scene 2, both) as within-subjects factors. A significant interaction between OE accuracy and question type, $F(1, 50) = 8.74$, $p < .001$, $\eta^2_p = .26$, required post hoc comparisons for each OE type. There was significantly less change deafness for correctly identifying change-relevant OE types compared to incorrectly identifying them (scene 1: $F(1, 27) = 47.81$, $p < .001$, $\eta^2_p = .64$; scene 2: $F(1, 27) = 65.65$, $p < .001$, $\eta^2_p = .71$).There was also a small but significant benefit for both OE types, $F(1, 25) = 5.21$, $p < .031$, $\eta^2_p = .17$ (see Figure 6). Again, participants who heard the uncued condition first had lower error overall in the omnibus ANOVA, $F(1, 25)= 7.91$, $p< .009$, $\eta^2_p= .24$ (see Figure 6), but no interactions with order reached significance (*p*s > .126). Finally, there was no benefit for correctly or incorrectly encoding neither OE types ($p <.508$).

Figure 6. Proportion of change detection error during uncued trials split by each OE type and OE accuracy. Error bars represent within-subjects confidence intervals.

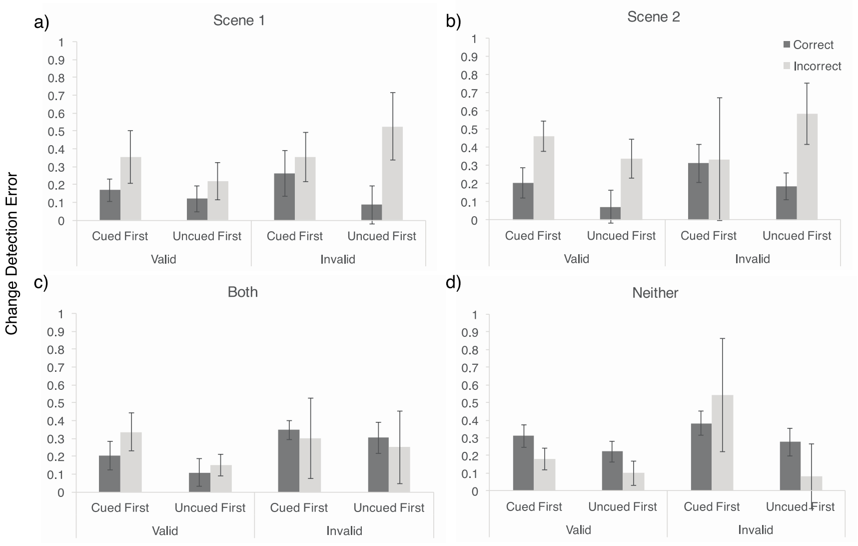


For the cued condition, mean change detection error was assessed with cue type (valid, invalid), OE accuracy (correct, incorrect), and OE type (scene 1, scene 2, both, neither) as within-subjects factors and condition order (cued first, uncued first) as a between-subjects factor. As a result of list-wise deletion (a standard method for handling missing data), the full omnibus ANOVA examining specific cue type could not be run because it resulted in the inclusion of only one participant. This was likely due to splitting the already uneven number of valid (n=19) and invalid (n=6) trials by OE accuracy. To examine whether successfully encoding auditory objects affected change detection during valid and invalid cue trials, we compared responses for each

OE type separately, which included cue type (valid, invalid), OE accuracy (correct, incorrect) and condition order (cued first, uncued first) as factors.

For scene 1, there was a main effect for OE accuracy, *F*(1, 22) = 10.44, *p* = .004 η^2_p = .32, showing that correctly identifying a scene 1 object resulted in less change detection error than failing to identify it. The only other significant effect was a 3-way interaction among order, cue type, and OE accuracy, *F*(1, 22) = 4.84, *p* = .039, η^2_p = .18. This indicated that when participants heard the uncued condition first there was less error for correctly compared to incorrectly encoded scene 1 objects for invalid trials, but no difference between OE responses for participants who heard the cued condition first (see Figure 7). Thus, change deafness was reduced for both orders when scene 1 objects were correctly identified during *valid* cue trials, but, during *invalid* cue trials, only participants who heard the uncued condition first showed an effect for correctly identifying a scene 1 object.

Figure 7. Proportion of change detection error during cued trials. Data are split by each OE type, cue type, and by OE accuracy. Error bars represent within-subjects confidence intervals.



For scene 2, a main effect of OE accuracy was again observed, $F(1, 12) = 8.41$, $p = .013$, $\eta^2_p = .41$, such that participants were better overall when they correctly encoded the scene 2 object. The only other significant effect was a cue type by order interaction, $F(1, 12) = 6.36$, $p = .027$, $\eta^2_p = .35$, which indicated that when accounting for object-encoding performance, change deafness was not different during valid and invalid trials overall when participants heard the cued condition first, but those who heard the uncued condition first had less change deafness on valid than invalid trials. This result is important as it may indicate that participants who heard the uncued condition first used a valid cue to notice and encode the sound unique to scene 2, whereas participants in the cued condition first may have simply attended to the presence or absence of the valid scene 1 object and failed to encode the new object in scene 2.

For the both OE type, there was no main effect for OE accuracy ($p = .679$), but there was a significant interaction between cue type and OE response, $F(1, 9) = 5.97$, $p = .037$, $\eta^2_p = .40$, such that correctly encoding the both OE question resulted in less change deafness during valid trials, but not during invalid trials, although this interaction is primarily due to participants who heard the cued condition first (see Figure 7). A significant interaction between order and cue type, $F(1, 9) = 6.17$, $p = .035$, $\eta^2_p = .41$, indicated that when object-encoding performance is taken into account, participants in the uncued condition first had less change deafness for valid compared to invalid trials, whereas no such benefit was observed for participants in the cued condition first.

Finally, for neither OE trials, a statistically significant main effect for order was found, $F(1, 8) = 28.89$, $p = .001$, $\eta^2_p = .78$, with greater change deafness overall for participants who heard the cued condition first.

Discussion

As in Experiment 1, invalid cues resulted in significantly greater change deafness than a valid cue and compared to no cue. However, in contrast to Experiment 1, a valid cue resulted in only a small reduction in change deafness compared to when we provided no cue. When comparing the experiments directly, there was less change deafness overall for Experiment 2 compared to Experiment 1, particularly for uncued and invalid cue trials. As the only difference between studies is the addition of the object-encoding task, this pattern suggests that the inclusion of this task biased listeners to attend to and encode individual objects and to spread their attention more broadly to monitor a larger number of objects. This is consistent with findings from the visual literature that show changes in attentional scope as a result of changes in task demands (Bleckley, Foster, & Engle, 2015; Yang, Little, & Hsu, 2014; Egly, Driver, & Rafal, 1994; LaBerge, 1983), with a broad attentional scope typically leading to enhanced change detection.

Further, an interesting and consistent effect of condition order was apparent in Experiment 2, but not Experiment 1. Participants who heard the uncued condition first had significantly less change deafness than those who heard the cued condition first. As such, participants seemed to adopt the first strategy they encountered during the experiment and maintained this strategy for the remainder of the study. That is, participants who heard the cued condition first may have had a narrow focus of attention even during the subsequent uncued condition, whereas participants who heard the uncued condition first may have adopted a broader scope of attention, even during the subsequent cued condition. This order effect was only present in Experiment 2, which suggests that adopting a broader attentional strategy is only possible when the listener has well-formed representations of individual objects within each scene, likely brought on by the requirement to encode individual objects in the object-encoding task. To our knowledge, this is the first evidence that a priming effect for a global or local attentional strategy can be induced by task demands in the auditory domain, whereas this type of effect has been observed previously in global vs. local visual detection tasks (e.g., Robertson et al., 1993).

Object-encoding performance revealed that participants were quite good at encoding individual objects within complex scenes, as has been previously reported (Gregg & Samuel, 2008; 2009; Gregg, Irsik, & Snyder, 2014). Without any direction of attention, participants were better at judging the presence of sounds that were unique to scene 2, heard in both scenes, or the absence of a sound from previous scenes. However, directing participants' attention toward a particular object within scene 1 altered their ability to encode other objects in the scene. In this experiment, a valid cue always directed attention toward a sound unique to scene 1, while an invalid cue always directed attention to a sound present in both scenes. As such, it makes sense that a valid cue resulted in lower error when identifying sounds unique to scene 1, while an invalid cue resulted in lower error when identifying sounds present in both scenes. Again, the condition order altered participants' performance, with those who heard the uncued condition first better able to recognize which objects were not present in either scene even during valid cue trials. This finding suggests that participants who heard the cued condition first encoded little else from the scene but the cued object.

Using object-encoding accuracy as another index of the locus of attention, we found that correctly identifying probed OE sounds resulted in less change deafness for the accompanying change detection task, especially for change-relevant OE types. These results highlight that trials in which the changing sounds were well encoded were also the trials in which listeners successfully detected a change. Further, participants who heard the uncued condition first had less change deafness when they correctly encoded change-relevant objects even during invalid trials, whereas participants who heard the cued condition first did not. Participants who heard the uncued block first maintained a broader scope of attention and naturally guided their own attention toward individual objects, allowing it to be "pulled" in a bottom-up manner by the changing object rather than "pushed" in a top-down manner by the exogenous direction of attention. Thus, adopting a strategy that broadly focuses attention toward multiple individual objects may increase participants' ability to encode and compare objects during the change detection task.

General Discussion

We found novel evidence supporting the notion that change deafness is highly dependent on attention. In particular, Experiments 1 and 2 showed that when listeners were given a cue toward a sound that does not change (an invalid cue) they were significantly less likely to notice the change. And when attention was directed toward the to-be-changed object in Experiment 1, change deafness was reduced compared to having no cue, but not completely eliminated. This latter effect was also markedly reduced in Experiment 2 when we added an object-encoding task. These results contradict previous findings that suggest change deafness can be eliminated when attention is directed to the changing object (Eramudugolla et al., 2005). Our findings may be inconsistent with previous work because our scenes were much shorter than Eramudugolla et al. (1 second vs. 5 seconds) and we replaced sounds that dropped out of scene 1. Thus, the stimuli of Eramudugolla et al. may have allowed participants to simply attend to an overall change in the acoustic energy or to have enough time to sequentially search the scene one object at a time to detect the missing object, resulting in the elimination of change deafness. Consistent with this interpretation, when items switched locations instead of disappearing from scene 1, Eramudugolla et al. reported error rates much more comparable to those reported here. Overall, our results for invalid cue trials mirror previous research in change detection (Posner et al., 1980; Rensink et al., 1997) and dichotic listening studies (Vitevitch, 2003), which propose that unattended objects have only weak representations in memory and are thus easily replaced by subsequent objects heard in the second scene or fail to be encoded altogether.

However, our findings diverged somewhat from Rensink et al. (1997) and Vitevitch (2003) when we examined how well objects were encoded within each scene during Experiment 2. With the addition of the object-encoding question, participants were likely biased to attend to multiple objects within each scene and this led to a decrease in change deafness overall. These results are consistent with previous studies that highlight the importance of encoding change-relevant objects for enhanced change detection (Gregg, Irsik, & Snyder, 2014). Additionally, participants' pattern of performance for change deafness, object encoding, and change deafness when split by object encoding accuracy suggested that participants adopted the strategy they encountered in their first block and carried it through the entire testing session, as has been demonstrated previously in the visual domain (Robertson, 1993). Specifically, participants who heard the uncued condition first adopted a broader scope of attention and those who heard the cued condition first adopted more of a narrow focus of attention. Taken together, a valid cue may not always be as beneficial for auditory change detection as has been observed in the visual domain. Indeed, when participants have strong representations of individual auditory objects and maintain a broad attentional strategy, listeners can achieve very low rates of change deafness (i.e., 16% compared to 26% for uncued trials and 15% compared to 23% for valid cue trials).

As in previous change deafness studies, we found that correctly identifying change-relevant objects resulted in less change deafness than when these same object types were not strongly represented in memory (Gregg, Irsik, & Snyder, 2014). We also found that objects were well-encoded overall in the uncued condition, but recency was an important factor for listeners' recall ability, as there was less error identifying sounds that were heard in the second scene (scene 2 and both OE types) compared to the first scene. Our findings regarding the effect of a cue on encoding were a bit more complex than initially predicted. While directing participants' attention often resulted in a failure to encode other objects within the scene, this effect was moderated by the validity of the cue. Valid cues led to more error encoding sounds that were not cued, but objects were well encoded for scene 2, neither, and both object-encoding types during invalid trials. Instead of participants exhibiting worse performance for scene 2 and neither trials when they heard invalid cues, it appears as though hearing two presentations of the sound that was cued during an invalid cue trial may have prompted participants to attend to and encode other elements within scene 2. Similarly, valid cues may have captured attention more fully when the cued object from scene 1 was no longer present in scene 2. For participants who heard the uncued condition first, objects had stronger representations in memory as evidenced by better awareness of sounds that were not present during the change detection task during invalid cue trials. As such, when listeners adopt a broad scope of attention and have formed strong representations of the individual sounds, they seem to be able to store and retrieve information from more objects in memory compared to those adopting a narrower scope of attention.

Additionally, these findings appear to be related to a reduction of stimulus-driven effects reported in both the change deafness (Gregg & Samuel, 2008; Dickerson & Gaston, 2014) and informational masking literature (Durlach et al., 2003; Lutfi, Chang, Stamas, & Gilbertson, 2012). Specifically, stimulus similarity (e.g., feature overlap between auditory objects) and stimulus uncertainty (e.g., difficulty predicting what the relevant auditory object will be) both contribute to detection failures by either leading to masking, interference, distraction by competing sounds, or because listeners are uncertain about which object is likely to change. Our results suggest that listeners were able to reduce effects of stimulus similarity by attending to the object level of analysis instead of the acoustic features at the local or global level. The effects of stimulus uncertainty were further reduced by adopting a broad scope of attention that captured multiple individual objects, allowing listeners to monitor all sounds within each scene.

A broader or more global attentional strategy may reduce change deafness overall, but we only saw this effect in Experiment 2, when objects had stronger individual representations in memory. Given the malleability of attentional scope for different tasks in the visual domain (e.g., Bleckley, Foster, Engle, 2015; Yang, Little, & Hsu, 2014; Egly, Driver, & Rafal, 1994; LaBerge, 1983), it seems that listeners who heard the uncued condition first were able to adopt an attentional strategy that enabled them to detect unpredictable changes by retaining object-level information for multiple objects. In future paradigms, it may be interesting to devise a secondary task that encourages listeners to process scenes as a single acoustic gestalt. Such a task might reduce change deafness even more so than our object-encoding task because attending to a single perceptual unit rather than four individual objects may reduce memory load. Thus, more research is needed to determine whether broad attention toward multiple auditory objects uniquely reduces change deafness or whether a gestalt strategy also reduces change deafness.

Our findings confirm the important role attention plays in detecting changes, but they also highlight the importance of being able to form strong representations for all potentially changing sounds within complex acoustic scenes. Thus, the detrimental effect of cueing attention toward a change-irrelevant sound might be lessened when listeners are biased toward attending to individual objects within the scene while adopting a broader attentional set.

Chapter 3: To What Extent Are Auditory Sensory Memory Processes Limited?

In addition to attentional limitations, listeners may also struggle to detect changes due to a limited ability to retain multiple objects in memory. For example, listeners may be constrained by a limited memory capacity or a loss of memory over time (e.g., information loss due to decay or sudden death). These two factors have been separately examined in the visual domain (e.g., Cornelissen & Greenlee, 2000; Luck & Vogel, 1997; Posner & Keele, 1967), and partly contribute to change blindness (Rensink, 2002). Evidence in favor of a capacity limited auditory system has been shown using a variety of paradigms. For example, studies using a serial recall task (Cowan, 2001), a sequential comparison task (Saults & Cowan, 2007), and a change deafness task (McAnally et al., 2010), have collectively reported substantive difficulty remembering and making comparisons as the number of task-related sounds increased. While an auditory capacity limit seems quite plausible (but see Brady, Störmer, & Alvarez, 2016; van den Berg, Awh, & Ma, 2014), it is unclear whether memory capacity interacts with the rate of memory loss over time, as has been shown in vision (Demany et al., 2008). More specifically, the rate that memory fades may increase when auditory memory capacity becomes increasingly taxed.

In fact, whether auditory memory fades over time at all has been a topic of debate. There have been conflicting reports, some which are in favor (Clement, Demany, & Semal, 1999; Demany et al., 2008; Kaernbach & Schlemmer, 2008), while others suggest auditory memory is either durable (Pavani & Turatto, 2008) or that interference is the sole cause of forgetting (Nairne, 2002). One factor which may contribute to this issue is that the sounds used in a particular study vary significantly, ranging from basic pure-tones to spectro-temporally rich environmental sounds. Another issue is that many studies that have examined this question have had methodological issues which limit the extent of their conclusions. For example, the typical design involves manipulating the delay interval between comparison sounds in a discrimination task, but with a short unchanging response interval. Therefore, performance decline at longer delay intervals could be from across-trial interference, due to pairing tones in memory between trials and not within trials (Cowan, Saults, & Nugent, 1997). These issues were thoroughly examined in the next chapter.

Chapter 4: Effects of Capacity Limits, Memory Loss, and Sound Type in Change Deafness[2]

Contribution: Second author; Conducted Experiment 2 and 3, and had a major role in data analysis and writing for all three studies.

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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 presented 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 detection to the natural sounds did not deteriorate much as the interval between scenes increased up to 2,000 ms, but it did deteriorate substantially with longer intervals. For artificial sounds, in contrast, change-detection performance suffered even for very

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short intervals. The results suggest that change detection is generally limited by capacity, regardless of sound type, but that auditory memory is more enduring for sounds with naturalistic acoustic structures.

Introduction

A surprising type of perceptual error that occurs during auditory tasks is the inability to detect large changes to objects in scenes. This phenomenon, known as change deafness (Eramudugolla, Irvine, McAnally, Martin, & Mattingley, 2005), is intriguing on a theoretical level because such large perceptual errors suggest fundamental limitations to our perceptual and mnemonic representations of the environment. Several lines of research on this topic have shown that change deafness (and its visual analog, change blindness) is partially dependent on attentional limitations (Rensink, O'Regan, & Clark, 1997) and on a limited capacity short-term/working memory (Luck & Vogel, 1997). However, it remains unclear whether loss of information over time, due to decay (Peterson & Peterson, 1959), interference (Keppel & Underwood, 1962), or sudden death (Zhang & Luck, 2009) is also a major contributing factor to change deafness, or for that matter to change blindness.

Multiple studies have provided evidence that change deafness is at least partly caused by a limitation in processing capacity, including limitations in attending to, encoding, or maintaining multiple sounds in auditory memory. For example, change deafness increases as the number of sounds within a scene is increased (Eramudugolla et al., 2005; McAnally et al., 2010). In addition, experimental manipulations that alleviate general processing constraints on change detection have been shown to reduce change deafness. Attentional limitations can be reduced by focusing attention via a valid cue indicating the name of the object that will change (Eramudugolla et al., 2005) or by presenting a cue indicating a particular spatial location where the change will occur (Backer & Alain, 2012). Capacity limitations are apparent in other auditory perception tasks as well, such as in auditory working memory tests (Li, Cowan, & Saults, 2013) and informational masking paradigms in which listeners are unable to identify a target tone in the presence of a masker that is distinct in frequency from the target (Durlach et al., 2003a,b). Collectively, these results suggest that capacity might limit perception of complex auditory scenes in general.

The extent to which other processing limitations contribute to change deafness is not well understood. For example, an additional cause of change deafness could be information loss over time. If the memory of the scene decays or is interfered with during the course of a trial, then change detection would fail. Information loss has not been systematically studied in change blindness, and there are only two research groups, to our knowledge, that have systematically investigated the issue of memory loss over time in change deafness. These research efforts have produced conflicting results. A series of experiments by Demany, Trost, Serman, and Semal (2008) provided evidence for information loss over time using simple stimuli. In one such experiment, listeners were presented with successive pairs of non-recognizable chords composed of several simultaneous pure tones, one of which could change on a given trial. The successive chords were separated by varying delays (ranging from 0 to 2000 ms) and composed of a varying number of pure tones (e.g., 4, 7, or 12). Demany et al. (2008) found that change detection performance declined as the number of pure tones within each chord increased and as the delay between chords increased, indicating important roles for processing capacity and information loss over time, respectively.

In contrast, a study using complex, naturalistic sounds demonstrated no apparent information loss over time (Pavani & Turatto, 2008). In this study, listeners were asked to detect changes to scenes of 3 or 4 animal sounds. The scenes were separated by 500 ms of silence, 500 ms of noise, or no delay interval, the latter to evaluate the potential role of auditory transients in change deafness rather than information loss. Change deafness rates were higher for scene sizes of 4 sounds than 3 sounds, but change deafness was just as prevalent with no delay interval between scenes as it was with a 500 ms silent or noise interval. This finding suggests that change deafness with natural sounds, which are more typically used in change deafness studies (see reviews by Dickerson & Gaston, 2014; Snyder & Gregg, 2011; Snyder, Gregg, Weintraub, & Alain, 2012), does not result from information loss over time.

These previous studies illustrate that there is not yet a clear answer as to whether change deafness is partly caused by information loss over time. One potential reason for the discrepancy across studies is that different types of stimuli were used. There is evidence outside the change deafness literature suggesting that stimulus type may modulate the encoding and the maintenance of auditory memories. Enhanced recognition memory has been shown to occur across a long interval with speech sounds relative to naturalistic sounds (Cohen, Horowitz, & Wolfe, 2009) and vocal melodies relative to piano melodies (Weiss, Vanzella, Schellenberg, & Trehub, 2015), which suggests specialized memory for particular types of familiar sounds. Electrophysiological data have also been reported showing that different categories of complex sounds are processed by distinct neural networks as early as 70 ms after stimulus onset (Murray et al., 2006). Together, these findings suggest that the auditory system has distinct mechanisms for processing certain classes of spectro-temporally complex sounds, which could lead to perceptual and memory advantages over more artificial sounds (for a similar finding in vision, cf. Brady, Störmer, & Alvarez, 2016).

In addition, the simple chord stimuli used in Demany et al. (2008) may not be appropriate for measuring general mechanisms of object memory loss over time in a change detection task. Such stimuli may allow for a specialized frequency-change detection mechanism that is sensitive to very small frequency changes (Demany et al., 2008). Thus, it is important to evaluate this issue using a variety of sound types, including simple, artificial sounds (such as pure tones and noise rhythms) and more naturalistic, complex sounds (sounds composed of multiple time-varying components) within the same paradigm. Comparisons across studies are also difficult, given the different range of delay intervals used: Pavani and Turatto (2008) only compared delay intervals of 0 ms and 500 ms, while Demany et al. (2008) tested a wider range of delay intervals (0 - 2000 ms). Thus, it is important to carefully evaluate this issue using multiple sound types and a comparable range of delay intervals.

In the present study, we address the contribution of capacity limitations and information loss on change deafness by using varying delay intervals and varying scene sizes with four sound types. Two types of artificial sounds were used to ensure that any pattern obtained with one type of artificial sound (e.g., noise rhythms) is generalizable to other artificial sounds (i.e., pure tone rhythms). Two types of naturalistic sounds were used: a set of recognizable environmental sounds, and a set of unrecognizable sounds. The unrecognizable sounds were scrambled versions of the recognizable sounds and were used to test for the potential of listeners relying on a verbal (or semantic) memory strategy. Though it is possible to affix verbal labels to non-verbal stimuli (see Braida, Lim, Berliner, & Durlach, 1984), our manipulation made it quite difficult to do so. If information loss over time is a major contributing factor to change deafness, then more change deafness should occur to all sound types as the delay interval between scenes is increased. If, on the other hand, auditory memory has extended storage time, then change deafness may not be affected by the delay interval between scenes. Furthermore, if memory representations of naturalistic, familiar sounds are more robust than representations for artificial, less familiar sounds, more change deafness would be expected to occur for artificial sounds compared to more natural sounds for larger delay intervals.

Experiment 1

Method

Participants. Forty-eight listeners with normal hearing participated in this experiment (24 females and 24 males; mean age = 19.4 years, range = 18 – 25 years). In this and in the following experiments, listeners were University of Nevada, Las Vegas (UNLV) undergraduates who received course credit for their participation. Sample size was chosen to be similar to or larger than what was used in other studies investigating scene size and scene delay (ISI) in an auditory change detection paradigm (e.g., Demany et al., 2008). All participants provided informed consent according to a protocol approved by the UNLV Office for Research Integrity.

Table 2. List of recognizable sounds used in Experiments 1-3.

Sounds	
Dog Barking	Motorcycle Engine
Chant	Owl Hoot
Man Coughing	Footsteps on Stairs
Baby Crying	Rocking Chair
Door Creaking	Knife Sharpening
Drum Beat	Train
Spoon Hitting a Frying Pan	Tuba Melody
Lighting a Match	

Stimuli. The naturalistic sounds consisted of recognizable and unrecognizable environmental sounds. The recognizable sounds consisted of 15 common environmental sounds, (e.g., a drill, drumming, a dog barking; see Table 2 for a complete list). The sounds were rated as highly recognizable in a previous study (Gregg et al., 2014). The duration of each sound was 1000 ms. All sounds were digitized to a sampling rate of 44.1 kHz, matched for RMS amplitude, filtered for noise, and a linear off-ramp to zero amplitude was imposed over the final 10 ms to avoid abrupt offsets. We chose not to impose on-ramps to better control the synchrony of sounds within a scene. All sounds were carefully examined to ensure there were no abrupt onsets. All stimuli were presented at a comfortable listening level (approximately 70 dB) in a sound attenuated chamber.

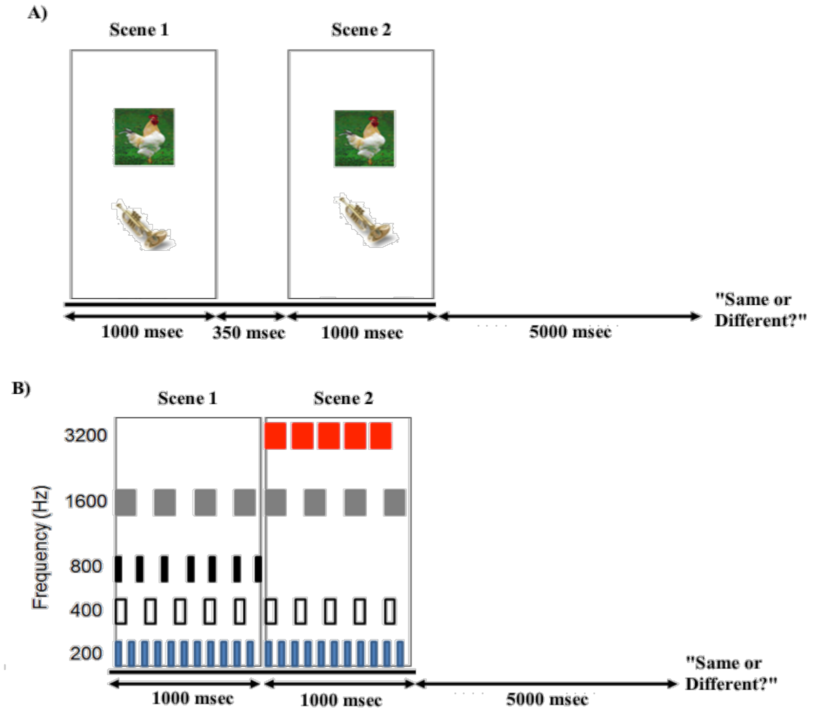
The stimuli were digitally combined to create unique scenes consisting of 2, 4, or 6 objects. Some acoustic properties of the scenes were equated by keeping the average acoustic spread among objects in the scenes similar. The average acoustic spread was created by calculating the Euclidean distance between pairs of stimuli based on 2 acoustic properties: fundamental frequency and harmonicity. We calculated the average acoustic spread for objects in both scene 1 and scene 2 by calculating the Euclidean distance between each pair of stimuli within each scene (all combinations of 4 objects resulted in 6 pairs) and then calculating the average acoustic distance between all pairs. The result was an average acoustic spread within Scenes 1 and 2. To obtain the acoustic measurements, each stimulus was submitted to Praat (Boersma & Weenink, 1992) for analysis of harmonicity (i.e., mean amount of acoustic periodicity in the signal measured as the ratio between the power of harmonics of the fundamental frequency to the power of non-harmonic components) and fundamental frequency (Gregg & Samuel, 2008). These two properties are particularly important for sound segregation: frequency is important given the tonotopic organization of the auditory system and is well-established as a strong cue to auditory scene analysis (e.g., Bregman, 1990); harmonicity is also a strong cue to auditory scene analysis (Yost & Sheft, 1993) and sounds have been found to be automatically and preattentively assigned to categories of periodic/aperiodic (Kat & Samuel, 1984). See also Gygi, Kidd, and Watson (2007) for the importance of these two dimensions.

A set of 15 unrecognizable sounds was created from the set of recognizable sounds. We achieved this by submitting each sound to a custom program created in MATLAb. The program split each sound into fifty 20-ms chunks, randomized the order of the chunks, and then connected the randomized chunks together into a new 1-second sound. The sounds were rated as reliably unrecognizable, as reported in a previous study (Gregg et al., 2014). As with the recognizable sounds, the unrecognizable stimuli were combined to create unique scenes with 2, 4, or 6 sounds that were equated in acoustic spread using the fundamental frequency x harmonicity space (fundamental frequency and harmonicity were re-measured from the scrambled sounds and those measurements were used to create a two-dimensional Euclidean space).

The artificial sounds consisted of simple pure tone rhythms and more spectrally complex noise burst rhythms. A set of 15 band-pass filtered white noise rhythms were created in Praat (Boersma & Weenink, 1992). Different rhythms were created by combining a series of noise bursts that were short (1/48 s), medium (1/24 s), or long (1/12 s) in duration. The noise bursts within a rhythm were interrupted by intervals of silence that were short (1/48 s), medium (1/24 s), or long (1/12 s) in duration. These parameters were adopted from a change deafness study using similar stimuli (Puschmann et al., 2013). The noise bands were centered at frequencies of 200, 400, 800, 1600, 3200 Hz, or 6400 Hz, with bandwidths set to 25% of the center frequency. Each 1000 ms noise rhythm was used to create scenes, each with a unique noise duration, silent interval duration, and frequency. The rhythms were combined to create unique scenes consisting of 2, 4, or 6 sounds. Within each scene, the noise rhythms were matched for loudness using loudness level contours (Fletcher & Munson, 1933). As with the natural sounds, the acoustic spread of the scenes was equated.

A set of 15 pure-tone rhythms were created in Praat (Boersma & Weenink, 1992) using the same durations, intervals, and frequencies as the noise rhythms, the only difference being that the noises were replaced by pure (i.e., sinusoidal) tones. The tone rhythms were combined to create unique scenes that were equated for difficulty and corrected for loudness as described above for the noise rhythms.

Figure 8. Trial schematic of the change-detection task. (A) An example of a Same trial composed of Recognizable sounds with a Scene Size of 2 and an ISI of 350 ms. (B) An example of a Different trial composed of pure tones with a Scene Size of 4 and ISI of 0 ms.



Procedure. Twelve different listeners completed the change detection task for each sound type: recognizable sounds, unrecognizable sounds, artificial noise rhythms, and artificial pure tone rhythms (the number of participants in each condition was selected to be comparable to previous investigations of memory loss in change deafness, see Demany et al., 2008; Pavani & Turatto, 2008). Figure 8 depicts example trials of the task. Listeners were presented on each trial with scene 1, a multiple-object scene in which the sounds were presented simultaneously for 1000 ms binaurally through Sennheiser HD 280 Pro headphones. Scene 1 was followed by scene 2, a 1000 ms scene consisting of either the same sounds as scene 1 (*same* trial) or all but one of the same sounds as scene 1 and one new sound (*different* trial). Three different levels of Scene Size (2, 4, or 6 objects) were orthogonally combined with four different levels of inter-scene interval (ISI: 0; 350; 750; 2000 ms). Each of the twelve combinations was presented in a separate block, resulting in twelve total blocks and 384 trials total There were 32 trials within each block, 16 Same trials and 16 Different trials. Each scene 1 was unique in terms of the combination of sounds from the set of 15 that were used. Listeners were instructed to indicate by button press whether scene 1 and scene 2 were the “same” or “different”. There was a 5000 ms inter-trial interval (ITI, the time from the offset of scene 2 to the onset of scene 1 of the next trial). Listeners performed 12 practice trials (one of each combination of Scene Size and ISI) before beginning the experiment.

Data analysis. In all experiments, responses were used to calculate the proportion of hits (responding “Different” on Different trials) and false alarms (responding “Different” on Same trials). The differencing strategy was used to obtain d′ scores (see Appendix A5.4 in Macmillan & Creelman, 2005). Prior to obtaining d’’, any conditions having proportions of either a 0 or 1 for false alarms or hits were corrected by replacing 0 and 1 values with 1/(2N) and 1-1/(2N) respectively, where N equals the total number of trials on which a proportion was based (Macmillan & Kaplan, 1985). The d′ scores were submitted to a three-way ANOVA with Sound Type (recognizable, unrecognizable, noise, or tones) as a between-subjects factor and Scene Size (2, 4, or 6 sounds) and ISI (0, 350, 750, or 2000 ms) as within-subject factors. Pair-wise comparisons on main effects used the Least-Significant Difference adjustment. Planned linear contrasts were used to follow up significant interactions to determine whether d′ dropped for each sound type individually. In all statistical tests, significance was reported using the Greenhouse-Geisser correction for all analyses. The significance criterion was $p < .05$.

Results and Discussion

Hit and false alarm rates from Experiment 1 are reported in Table 3. Change-detection performance differed by Sound Type, $F(3, 44) = 3.77$, $p = .017$, $\eta^2_p = .20$. Change detection was significantly worse for the naturalistic sounds: planned comparisons indicated significantly more change detection errors (i.e., change deafness) in response to unrecognizable and recognizable sounds than to the noises or tones (ps $< .05$). Change detection across all sound types was affected by the number of sound objects, which indicates that capacity limitations have a general effect on change detection. As can be seen in Fig. 9, change-detection performance decreased as the number of sound objects increased, $F(2, 88) = 226.26$, $p < .001$, $\eta^2_p = .84$. Planned comparisons indicated that change detection was worse when the scene size was six sounds (mean d′ =3.43, SD = 0.95) than when the scene size was four sounds (mean d′ = 4.24, SD = 1.07, $p < .05$), and two sounds (mean d′ = 5.57, SD = 1.14, $p < .05$).

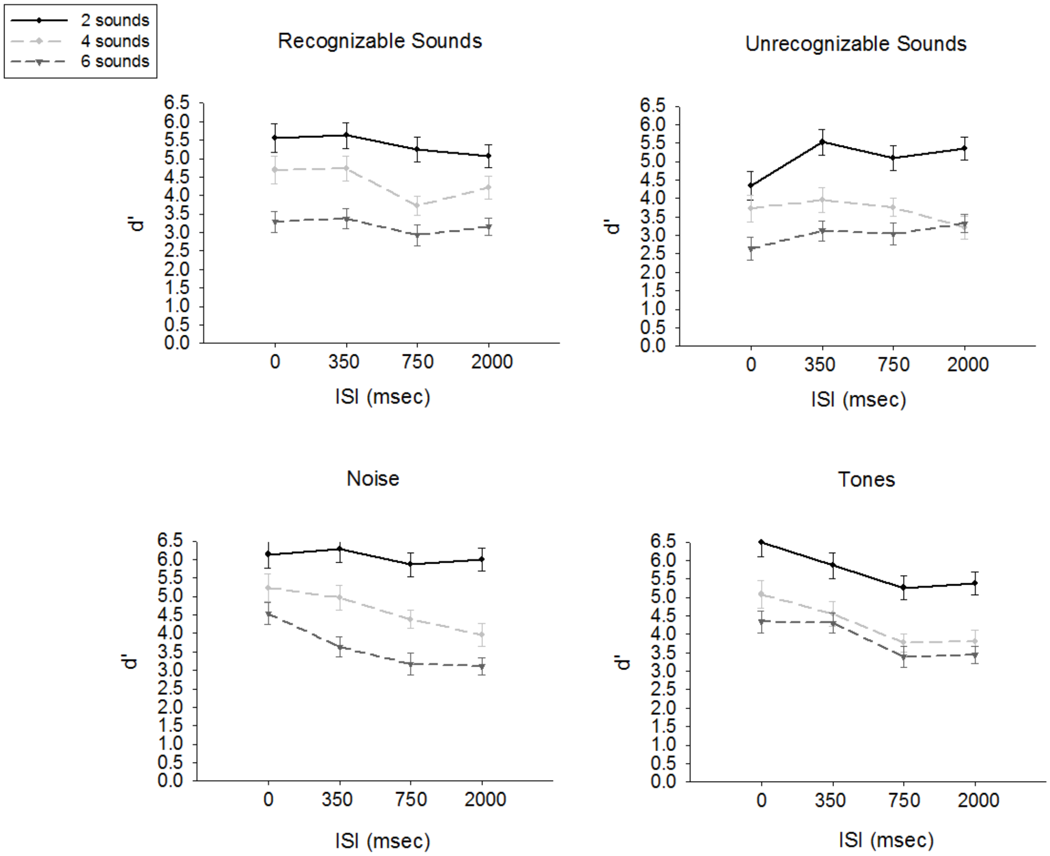
Change detection was also affected by the delay between scenes: there was a significant effect of ISI, $F(3, 132) = 16.89$, $p < .001$, $\eta_p^2 = .28$. This finding suggests that information loss over time contributes to change detection errors; however, an interaction between ISI and Sound Type, $F(9, 132) = 4.89$, $p <.001$, $\eta^2_p = .25$, revealed that information loss only affected change detection to certain sound types. Planned linear contrasts indicated that the ISI significantly influenced change detection only to the artificial sounds (i.e., tones and noise rhythms). Change detection performance to the scenes composed of tones and noise rhythms was worse at the 750-ms and 2,000-ms ISIs than at the 0-ms and 350-ms ISIs (ps $< .05$).

Table 3. Hit and false alarm rates from experiment 1.

	Recognizable	Unrecognizable	Noise	Tones
0 ms ISI				
2 sounds				
Hits	0.90	0.89	0.97	0.95
False Alarms	0.08	0.17	0.07	0.03
4 sounds				
Hits	0.80	0.71	0.95	0.88
False Alarms	0.05	0.12	0.12	0.07
6 sounds				
Hits	0.55	0.53	0.82	0.81
False Alarms	0.06	0.17	0.09	0.08
350 ms ISI				
2 sounds				
Hits	0.89	0.86	0.96	0.93
False Alarms	0.05	0.05	0.05	0.04
4 sounds				
Hits	0.77	0.66	0.86	0.74
False Alarms	0.04	0.05	0.06	0.04
6 sounds				
Hits	0.62	0.45	0.65	0.71
False Alarms	0.08	0.04	0.07	0.04
750 ms ISI				
2 sounds				
Hits	0.91	0.87	0.95	0.91
False Alarms	0.07	0.06	0.07	0.07
4 sounds				
Hits	0.76	0.64	0.85	0.74
False Alarms	0.09	0.07	0.11	0.07
6 sounds				
Hits	0.55	0.47	0.64	0.64
False Alarms	0.07	0.05	0.13	0.08
2000 ms ISI				
2 sounds				
Hits	0.89	0.89	0.96	0.92
False Alarms	0.09	0.05	0.06	0.06
4 sounds				
Hits	0.74	0.63	0.84	0.70
False Alarms	0.05	0.09	0.1	0.06
6 sounds				
Hits	0.56	0.54	0.6	0.63
False Alarms	0.07	0.06	0.1	0.08

For the recognizable and unrecognizable sounds, there were no significant differences in change-detection performance across the four ISIs. The three-way interaction among ISI, Sound Type, and Scene Size was not significant, $F(18, 264) = 1.03$, $p = .431$, $\eta^2_p = .06$. Thus, although capacity limitations seem to have a general effect on change detection, the role of information loss in change detection seems to be specific to artificial sounds, and more complex environmental sounds appear to be relatively resistant to information loss over time. This latter finding is admittedly restricted to a time course spanning 2,000 ms. Experiment 2 was conducted to examine potential information loss over a longer time period.

Figure 9. Change detection performance to all sound types in Experiment 1 (measured by d′). Error bars represent the standard error of the mean.



Experiment 2

Experiment 1 demonstrated that change deafness to complex, naturalistic sounds is not due to information loss over time, with delays ranging from 0 ms to 2,000 ms. Experiment 2 was conducted to examine whether change-detection performance for such sounds remains unaffected by longer delays between scenes. In this experiment, we determine whether information is lost during a change-detection task when the delay is as long as 6,000 ms.

Method

Participants. Fifty-two listeners with normal hearing participated in this experiment (28 females and 24 males; mean age = 20.32 years, range = 18 - 35 years). Data from four participants were not included in analyses due to prior health history (n=1, brain tumor), technical malfunction (n=2), or because they pushed buttons randomly (n=1). A total of forty-eight participants (12 in each condition) were included in statistical analyses.

Stimuli. Stimuli were identical to Experiment 1.

Procedure. The procedure was identical to Experiment 1, except different ISIs were used (0; 100; 750; 6000, instead of 0; 350; 750; 2000 ms).

Results and Discussion

Hit and false alarm rates from Experiment 2 are reported in Table 4. As in Experiment 1, change detection performance was worse for the naturalistic sounds. This was indicated by an effect of Sound Type, F (3, 44) = 14.36, $p < .001$, $\eta^2_p = .50$, as well as planned comparisons indicating more change detection errors in response to unrecognizable and recognizable sounds than to the noises and tones, *p-values* < .05.

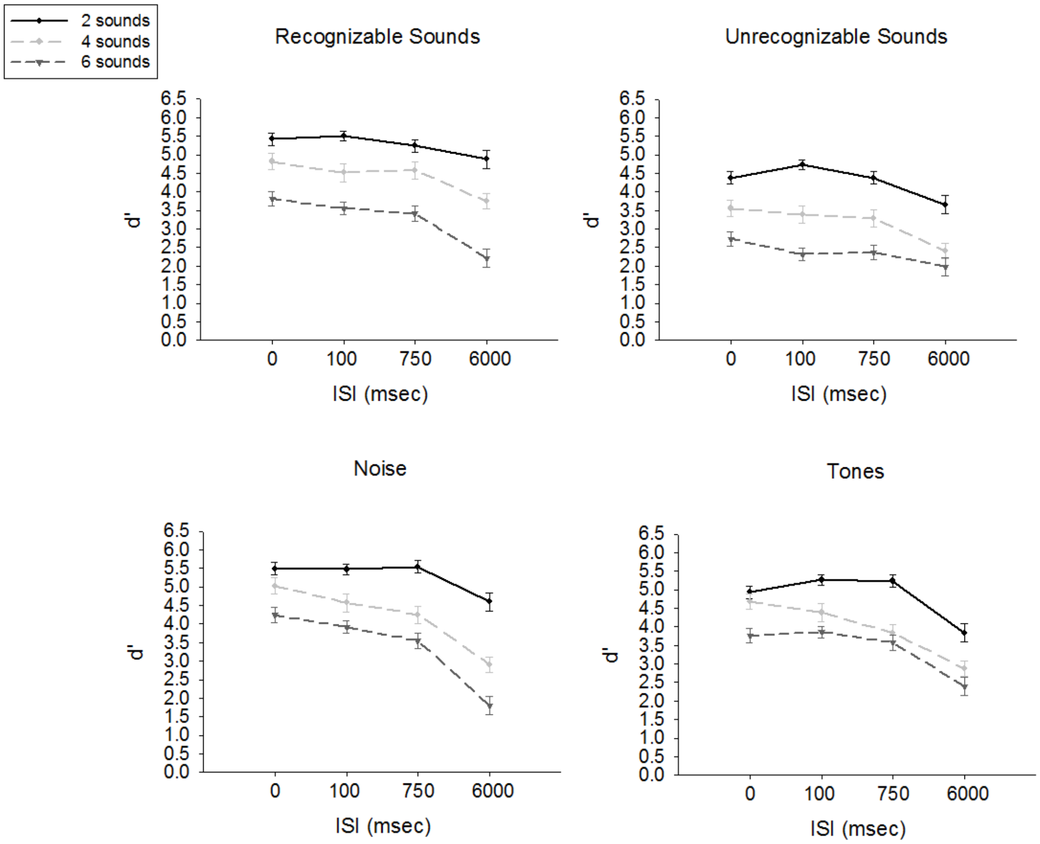
Table 4. Hit and false alarm rates from experiment 2.

	Recognizable	Unrecognizable	Noise	Tones
0 ms ISI				
2 sounds				
Hits	0.96	0.86	0.96	0.93
False Alarms	0.05	0.07	0.04	0.07
4 sounds				
Hits	0.87	0.69	0.93	0.90
False Alarms	0.04	0.07	0.05	0.07
6 sounds				
Hits	0.73	0.50	0.82	0.77
False Alarms	0.05	0.08	0.05	0.08
100 ms ISI				
2 sounds				
Hits	0.96	0.89	0.95	0.93
False Alarms	0.04	0.06	0.04	0.04
4 sounds				
Hits	0.85	0.64	0.84	0.85
False Alarms	0.04	0.05	0.04	0.06
6 sounds				
Hits	0.69	0.41	0.74	0.73
False Alarms	0.06	0.08	0.04	0.04
750 ms ISI				
2 sounds				
Hits	0.94	0.85	0.96	0.94
False Alarms	0.05	0.08	0.04	0.05
4 sounds				
Hits	0.86	0.63	0.79	0.69
False Alarms	0.04	0.06	0.04	0.03
6 sounds				
Hits	0.67	0.41	0.65	0.64
False Alarms	0.06	0.07	0.04	0.03
6000 ms ISI				
2 sounds				
Hits	0.95	0.82	0.94	0.86
False Alarms	0.10	0.17	0.17	0.17
4 sounds				
Hits	0.80	0.61	0.76	0.68
False Alarms	0.10	0.21	0.26	0.17
6 sounds				
Hits	0.60	0.56	0.56	0.62
False Alarms	0.21	0.21	0.27	0.20

Also consistent with Experiment 1, change detection across all sound types was affected by the number of sound objects, indicating again that capacity limitations have a general effect on change detection (see Figure 10). This finding was indicated by an effect of Scene Size, F (2, 88) = 414.46, $p < .001$, $\eta^2_p = .90$. Planned comparisons indicated that change detection performance was lower when the scene size was 6 sounds (mean d′ =3.09, SD = 0.71) than when scene size was 4 sounds (mean d′ = 3.93, SD = 0.78), $p < .05$, and 2 sounds (mean d′ = 4.91, SD = 0.62), *p-values* < .05. Change detection was also affected by the delay between scenes, as indicated by a significant effect of ISI. Mauchly’s test indicated that the assumption of sphericity had been violated, therefore p values were corrected using Greenhouse-Geisser estimates of sphericity: F (3, 132) = 144.36, $p < .001$, $\eta^2_p = .77$. There was also an interaction between ISI and Sound Type, F (9, 132) = 3.94, $p < .001$, $\eta^2_p = .21$ and a three-way interaction between ISI, Sound Type, and Scene Size, F (18, 264) = 2.12, $p = .006$, $\eta^2_p = .13$. Planned linear contrasts on the three-way interaction indicated that the interaction was driven by the marked drop in change detection performance at the 6000 ms ISI, especially at larger scene sizes (see Figure 10).

For all sound types and all scene sizes, performance was significantly worse during the 6000-ms delay than during the shorter delays (0, 100, and 750 ms). This finding suggests that the effect of ISI is more general across sound types when longer delay intervals are examined. However, one potential problem in Experiment 2, that was not observed in Experiment 1, was a high false alarm rate for trials with a 6000 ms ISI (mean = 23.9%, compared to a false alarm rate of 11% for the longest ISI in Experiment 1). This could have occurred because the inter-trial interval for long ISI trials was actually shorter than the delay interval between scenes (ITI was held constant at 5000 ms). This may have caused Scene 2 to become paired in memory with Scene 1 of a new subsequent trial as a result of closer temporal proximity (cf. Cowan, Saults, & Nugent, 1997), which would in turn cause interference during discrimination judgments. Therefore, Experiment 3 was conducted to address this concern.

Figure 10. Change detection performance to all sound types in Experiment 2 (measured by d′). Error bars represent the standard error of the mean.



Experiment 3

Experiment 3 was conducted to further explore the general effect of the delay between scenes found in Experiment 2. Specifically, this experiment allowed us to determine whether the decrease in change detection performance at longer delays for all sound types was a result of information loss, rather than an artifact of across-trial interference (cf. Cowan, Saults, & Nugent, 1997). In Experiment 3, we modified the paradigm used in Experiment 2 to better control the ISI:ITI ratios.

Method

Participants. Fifty-two listeners with normal hearing participated in this experiment (39 females and 13 males; mean age = 20.76 years, range = 18 - 35 years). Data from four participants were not included in analyses due to prior health history (n=3, multiple sclerosis, head injury, and seizures), or because they pushed buttons randomly (n=1). A total of forty-eight participants (12 per sound type) were included in statistical analyses.

Stimuli. Stimuli were identical to Experiment 1.

Procedure. The procedure was nearly identical to Experiment 1. In this experiment, different ISIs were used: 0; 100; 1500; 6000 ms. Inter-trial intervals (ITI) were also changed in order to retain temporal distinctiveness of Scene 2 to Scene 1 of a following trial, and to have constant ISI:ITI ratios for at least two ISI conditions. The ITI was set to 2000 ms for ISI conditions with shorter delays (0, 100, 1500), and 8000 ms for the longest ISI condition (6000 ms), allowing the 1500 and 6000 ms conditions to have an equivalent ISI:ITI ratio (3:4). It was not possible to have the same ratios for the two shortest ISIs because the resulting ITIs would not be long enough for participants to respond.

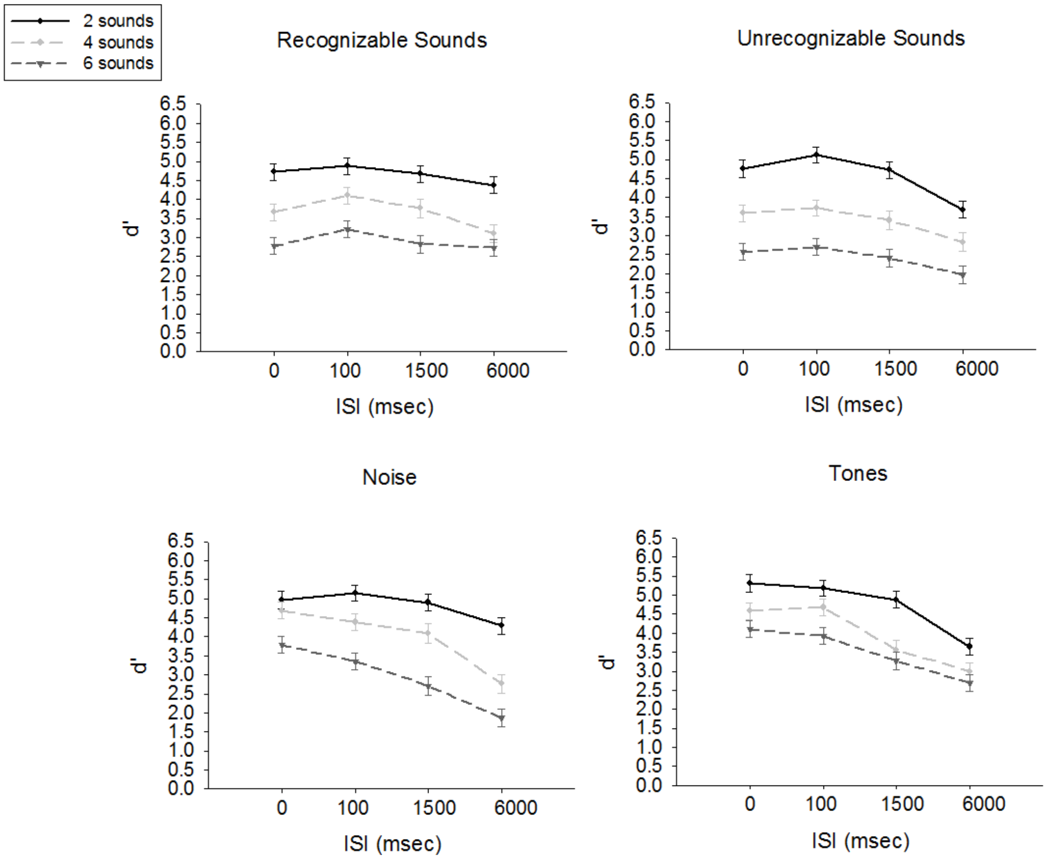
Results and Discussion

Hit and false alarm rates are reported in Table 5. Consistent with Experiments 1 and 2, change detection performance was worse for the naturalistic sounds: there was a significant effect of Sound Type, F (3, 44) = 3.69, p = .019, η^2_p = .20. Planned comparisons indicated lower change detection performance in response to unrecognizable and recognizable sounds than to the noises and tones, *p values* < .05.

Table 5. Hit and false alarm rates from experiment 3.

	Recognizable	Unrecognizable	Noise	Tones
0 ms ISI				
2 sounds				
Hits	0.87	0.90	0.95	0.95
False Alarms	0.05	0.06	0.11	0.05
4 sounds				
Hits	0.73	0.71	0.92	0.86
False Alarms	0.08	0.07	0.08	0.06
6 sounds				
Hits	0.52	0.43	0.77	0.78
False Alarms	0.07	0.06	0.10	0.04
100 ms ISI				
2 sounds				
Hits	0.89	0.92	0.94	0.93
False Alarms	0.06	0.03	0.05	0.04
4 sounds				
Hits	0.76	0.69	0.86	0.83
False Alarms	0.04	0.04	0.08	0.03
6 sounds				
Hits	0.60	0.43	0.61	0.77
False Alarms	0.06	0.04	0.04	0.06
1500 ms ISI				
2 sounds				
Hits	0.90	0.87	0.92	0.89
False Alarms	0.07	0.03	0.07	0.04
4 sounds				
Hits	0.71	0.61	0.80	0.66
False Alarms	0.06	0.04	0.06	0.05
6 sounds				
Hits	0.54	0.37	0.50	0.60
False Alarms	0.07	0.04	0.07	0.04
6000 ms ISI				
2 sounds				
Hits	0.90	0.86	0.94	0.88
False Alarms	0.10	0.20	0.19	0.24
4 sounds				
Hits	0.68	0.67	0.78	0.74
False Alarms	0.13	0.16	0.32	0.19
6 sounds				
Hits	0.63	0.52	0.64	0.74
False Alarms	0.17	0.18	0.36	0.29

Figure 11. Change detection performance to all sound types in Experiment 3 (measured by d′). Error bars represent the standard error of the mean.



Change detection across all sound types was affected by the number of sound objects, indicating again that capacity limitations have a general effect on change detection. As can be seen in Figure 11, change detection performance decreased as the number of sound objects increased, F (2, 88) = 248.45, $p < .001$, $\eta^2_p = .85$. Planned comparisons indicated that change detection performance was lower when the scene size was 6 sounds (mean d′ =2.93, SD = 0.8) than when the scene size was 4 sounds (mean d′ = 3.75, SD = 0.79), $p < .05$, and 2 sounds (mean d′ = 4.70, SD = 0.73, $p < .001$).

As in Experiment 1, change detection was affected by the delay between scenes composed of artificial sounds, and less so to natural, complex sounds: this was indicated by a significant effect of ISI, F (3, 132) = 80.71, $p < .001$, $\eta_p^2 = .65$, an interaction between ISI and

Sound Type, F (9, 132) = 4.94, $p < .001$, $\eta_p^2 = .25$, and a three-way interaction between ISI, Sound Type, and Scene Size, F (18, 264) = 1.73, $p = .034$, $\eta_p^2 = .11$. Planned comparisons to explain the three-way interaction indicated that change detection performance during the recognizable and unrecognizable scenes was relatively similar across the three shorter ISIs (0, 100, and 1500 ms), but dropped significantly at the 6000-ms ISI (*p-values* < .05). Change detection performance during the scenes composed of noise and tone rhythms dropped more linearly as ISI increased, (d′ at 0 and 100 ms was higher than at 1500 and 6000 ms, $p < .05$, and d′ at 1500 ms was higher than at 6000 ms, $p < .05$).

General Discussion

In this study, we examined the contribution of capacity limitations and information loss over time to change deafness during scenes composed of four different sound types: recognizable environmental sounds, unrecognizable environmental sounds, tone rhythms, and noise rhythms. The results of the present study consistently revealed that a capacity limitation contributes to change deafness for all sound types. This finding is consistent with a large body of perceptual research demonstrating that attention, perception, and memory are all limited by the number of objects that can be simultaneously processed. For example, our ability to consciously detect auditory targets in complex backgrounds is limited by the number of competing sounds, a phenomenon referred to as informational masking (Dickerson & Gaston, 2014; Durlach et al., 2003; Lutfi, Chang, Stamas, & Gilbertson, 2012). Though the existence of a fixed limit in working memory has been challenged (see van den Berg, Awh, & Ma, 2014; Brady, Störmer, & Alvarez, 2016), the results of the present study indicate a novel difference between auditory and visual working memory that should be noted. Recent evidence in the visual domain suggests that visual working memory has a larger capacity for naturalistic objects, compared to artificial objects (Brady, Störmer, & Alvarez, 2016). Our results suggest that the capacity of auditory memory is similar for naturalistic and artificial sounds (though the duration that these stimuli can be maintained in auditory memory does differ, as we discuss below). One important endeavor for future research is to further explore this potential difference in the way that auditory memory and visual memory store information, the role of stimulus complexity in storage, and the stages of processing in which the capacity limitation in change deafness (and change blindness) arises.

The results of the present study suggest that change deafness occurs not only because of limitations in auditory memory processing capacity, but also because of loss of information in memory, especially for artificial sounds. Change detection of the recognizable and unrecognizable environmental sounds did not vary much as a function of the delay interval between scenes if the interval was 2000 ms or less. Only when the interval between scenes was extended to 6000 ms did change detection performance to the environmental sounds decline substantially (in Experiments 2 and 3). Change detection of the artificial sounds, i.e., tones and noise bursts, was more affected by the increasing interval between scenes, and this was despite the fact that overall change detection performance was better for artificial sounds. The differences in detection of changes to artificial and environmental sounds suggest that change detection for environmental, spectrally complex sounds has access to memory mechanisms that are more persistent than those for artificial sounds. This finding is somewhat at odds with other discrimination or segregation studies which show a more gradual decline in auditory short-term or implicit memory over long intervals for artificial sounds; however, performance during these studies may have been aided by the use of even simpler sounds perceived as one (McKeown & Mercer, 2012; Mercer & McKeown, 2014) or two objects (Snyder & Weintraub, 2013). Given that the memory load would be minimal for comparing so few objects, it may have been easier to maintain stimulus details in memory for longer periods of time. This is consistent with our findings, as listeners had significant difficulty comparing larger scene sizes when the delay interval was long. One important endeavor for future research will be to determine why there are differences in the way auditory memory retains environmental and artificial sounds. For example, environmental sounds may recruit larger neural populations than artificial sounds, which could contribute to the differences in representational strength. A related possibility is how the varying degrees of spectral overlap in environmental and artificial sounds contribute to change deafness.

The more surprising finding of this study was that change deafness to environmental sounds was not affected much by the delay interval between scenes when the interval was as long as 2000 ms. We suggest that although auditory short-term memory capacity is limited, memory for naturalistic sounds is remarkably enduring, and information loss over time (e.g., due to decay, interference, or sudden death) does not cause change deafness to natural sounds up to 2000 ms. Given the present results, efforts to improve auditory change detection in natural settings should boost processing capacity more so than the ability to retain information over short amounts of time. It is worth noting that the duration of each scene in this study was held constant at 1000 ms. There are studies suggesting different types of memory encoding strategies in response to short stimuli at short ISIs than to long stimuli at long ISIs (McDermott, Schemitsch, Simoncelli, 2013), as well as evidence that scene length can affect change deafness (Eramudugolla, McAnally, Martin, Irvine, Mattingley, 2008; McAnally et al., 2010). It will be important for future research to determine how information loss is affected in a change detection task when both scene duration and ISI are manipulated. Future studies should also determine if information loss over time affects change blindness; to our knowledge, the delay between scenes has not been systematically manipulated in a change blindness paradigm.

Information loss to all sound types was apparent when the delay interval between scenes was extended to 6000 ms: this loss was particularly large at larger scene sizes. The constant ITI ratio in Experiment 3 suggests that the drop in successful change detection performance from 2000 to 6000 ms was a result of true information loss, through decay or sudden death, rather than interference. Recent research on auditory memory suggests that one potential reason for the information loss is an inverse relationship between the number of objects in auditory working memory and the fidelity of each object representation (Joseph, Kuman, Husain, & Griffiths, 2015). If this were the case in the present study, then increasing the delay between scenes would be more detrimental to performance as scene size increases because the quality of the object representations at scene sizes of 6 sounds would be poorer than representations of 2 or 4 sound objects. Other recent work on auditory memory has revealed that memory is better when an integrated auditory object must be held in auditory memory, rather than auditory features (Joseph et al., 2015). This finding could explain why increasing the delay interval was more detrimental to performance when the sounds were simple noise and tone rhythms, as it is possible that listeners are more likely to consider natural sounds as auditory "objects", even if they are unrecognizable. Also, the complexity and multiple segregation cues in the auditory "objects" could create more durable representations. It should be noted that while listeners were better able to hold environmental sounds in memory relative to artificial sounds, they had more difficulty remembering unrecognizable relative to recognizable environmental sounds over long intervals. It is possible that the scrambled temporal structure of unrecognizable sounds made it difficult to appropriately group acoustic details and form objects on more difficult trials, motivating listeners at times to focus on auditory features.

The results of the present investigation indicate a potential difference in the auditory and visual memory processes that support change detection. A well-demonstrated finding in vision is accurate change detection performance at very short delays between scenes (less than 100 ms) that is not affected by the number of objects in the display. However, once the delay between scenes exceeds 100 ms, change detection performance begins to decline as the number of objects within the scenes increase (Phillips, 1974). Better change detection performance at short delays presumably reflects an unlimited-capacity, short-duration sensory memory; meanwhile, performance at longer delays that declines with increasing scene sizes reflects a limited-capacity, long-duration visual working memory system (Luck & Vogel, 1997).

In audition, however, a similar interaction does not occur. There was no interaction between scene size and the delay interval between scenes in Experiments 1 and 3 of this study: Demany et al. (2008) also failed to find an interaction between scene size and the delay interval between scenes in several auditory change detection experiments. The different pattern of results in vision and audition do not necessarily mean that there are fundamental differences in the visual and auditory memory processes that support change detection. For example, it is possible that visual and auditory change detection mechanisms are essentially the same or at least analogous, but different patterns emerge because auditory sensory memory is longer-lasting than visual sensory memory (Demany et al., 2010). The difference in auditory and visual sensory memory is well-suited for the nature of auditory and visual stimuli. Sounds are quite transient and need to be held in memory in order to be temporally integrated with subsequent sounds. Without this ability, it would be nearly impossible to understand a spoken sentence, or to organize and integrate continuous sounds as coming from a single source. Temporal integration of auditory information requires a long-duration sensory storage, but visual objects can typically be viewed for extended periods of time, making a long sensory storage unnecessary.

An additional possibility is that there is not as sharp a distinction between auditory sensory and short-term/working memory (e.g., Jones, Hughes, & Macken, 2006; Nicholls & Jones, 2002) as there is in vision. Another issue to consider is that visual stimuli in change detection paradigms are usually static, unlike sounds, which are dynamic. It will be important for future visual change detection studies to compare performance to static (e.g., pictures) and dynamic (e.g., videos) stimuli to further explore the issue of whether auditory and visual change detection processes are similar.

In summary, change deafness to environmental sounds is largely due to a capacity limitation and not loss of memory, except when using intervals of a few seconds or more. Change deafness to simple, artificial sounds, however, is caused by capacity limitations and loss of memory over time, even for short intervals between scenes. Previous investigations of change deafness have limited manipulations to only artificial sounds (e.g., Cervantes Constantino, Pinggera, Paranamana, Kashino, & Chait, 2012) or to only naturalistic sounds (e.g., Vitevitch, 2003). The present investigation is the first study, to our knowledge, to directly compare change detection performance to spectrally complex environmental sounds and spectrally simple artificial sounds: a comparison that allowed us to address the extent to which memory loss occurs in change deafness tasks with different stimuli. The differences in change detection performance to the different sound types found in this experiment demonstrate the importance of using multiple sound types to fully understand the mechanisms underlying change deafness.

Chapter 5: Does Change Deafness Represent a Fundamental Limitation of the Auditory System?

Studying change deafness has been an important endeavor for two reasons. First, it provides a means for understanding how listeners naturally organize complex environments. This is important from a theoretical perspective as it advances current understanding of how the auditory system functions. Secondly, there are many everyday tasks which rely on auditory information to perform, not to mention a variety of professions which depend on perceptual accuracy to ensure safety (e.g., military, law enforcement, etc.). Yet, change deafness represents a substantial limitation to auditory scene analysis processes. An effective training program would therefore be valuable to a wide range of individuals, and determining the factors which result in a missed change could provide a roadmap of processes to target. It is possible that change deafness represents a fundamental limitation of the auditory system that cannot be substantially modified. In this case, investigating training would be useful in determining a functional limit of auditory change detection potential.

Since the acoustic content of an auditory scene is a strong determinant of change detection accuracy (e.g., Gregg & Samuel, 2008), targeting scene segregation processes may be a good starting point. One training strategy may be to practice a skill which supports auditory scene analysis, thereby altering the process that supports change detection. For example, using a task which asked participants to listen for a target in multi-talker babble may be useful in promoting enhanced segregation processes (e.g., coordinate response measure target identification tasks; Brungart, 2001). However, using a separate task to improve change detection runs the risk that the strategy used to succeed during the training task may not generalize. Another strategy would be to have participants practice change detection, and to offer a strategy to improve scene analysis. This was addressed in the next and final manuscript.

Chapter 6: Change Deafness Can Be Reduced, But Not Eliminated, Using Brief Training Interventions

Contribution: First author

Status: Submitted in 2018 to Journal of Experimental Psychology: Applied; Under Review

Abstract

Research on *change deafness* indicates there are substantial limitations to listeners' perception of which objects are present in complex auditory scenes, an ability that is important for many professions. We examined the extent to which change deafness could be reduced by comparing the efficacy of training with detailed feedback, training without feedback, and no training at all. We also determined the timescale during which training-induced improvement occurred by examining performance at two separate time points after training. Learning was observed for all groups, although the full benefits of training were not fully observable until hours later. Training with feedback was most effective at reducing change deafness, although significant learning also occurred for listeners that trained without feedback. The control group also showed learning, suggesting an effect of simply testing. Together, these findings suggest that auditory change detection can be enhanced relatively rapidly, although the training regimen type can determine whether improvement occurs immediately (fast learning) or if learning continues to develop hour after training ceased (slow learning).

Introduction

Auditory perception in real-world situations can be challenging due to inherent processing constraints of the auditory system and the overall complexity of most listening environments. When there are multiple co-occurring sounds, the individual waveforms sum together as they enter a listener's ear and stimulate the cochlea as a single amalgamation. Consequently, a major function of the auditory system is to perceptually segregate simultaneous sounds to form individual auditory objects, each of which represents sound information emanating from a single source. This is considered possible through a process called *auditory scene analysis* (Bregman, 1990), during which listeners use feature regularities (e.g., timbre, rhythm, pitch) as a cue for segregating and integrating auditory information. However, there is a growing literature on the phenomenon of change deafness (e.g., Vitevitch, 2003; see reviews Dickerson & Gaston, 2014; Snyder & Gregg, 2011; Snyder, Gregg, Weintraub, & Alain, 2012), the inability to detect auditory changes in complex listening situations, which has raised the question of how accurately listeners represent the environment.

Much of the research on change deafness has been motivated by reports on its well-studied visual analogue, change blindness (Simons, 1996; Simons & Rensink, 2005). A popular method for examining change deafness is the one-shot paradigm adapted from the visual domain (e.g., Levin & Simon, 1997). During the task, participants hear two groups of sounds that are separated by a brief period of silence (Gregg, Irsik, & Snyder, 2014) or noise (Gregg & Samuel, 2008; Gregg & Samuel, 2009; Pavani & Turatto, 2008), after which they are asked to make a same/different judgement. The two groups of sounds either contain identical content (same trial), or a sound in the second group has either been deleted (Constantino, Pinggera, Paranamana, Kashino, & Chait, 2012), replaced (Gregg & Samuel, 2008; Gregg & Samuel, 2009; Gregg &

Snyder, 2012), or has switched locations with another object (Eramudugolla, Irvine, McAnally, Martin, & Mattingley, 2005) (different trial). Error rates during different trials are quite high and typically range from 30-55%. Error rates during same trials are characteristically low and usually fall under 10%. Thus, the term ‘change deafness’ refers to the fact that listeners are mostly struggling to detect changes, but do not make false alarms during same trials.

Thus far, there is a substantial amount of overlap in the factors that contribute to change detection errors in the visual and auditory domains. For example, one major reason that a change can fail to reach awareness is that change-relevant objects were poorly encoded (Beck & Levin, 2003; Gregg et al., 2014; Irsik, Vanden Bosch der Nederlanden, & Snyder, 2016; Noë, Pessoa, & Thompson, 2000; but see Mitroff, Simons, & Levin, 2004). Attentional limitations play a major role in determining which objects will be encoded and which objects may be overwritten in memory or ignored. The effect of attention on change detection has been examined by cueing participant’s attention either to an object that will change (valid cue) or to an object that will not change (invalid cue), and comparing performance to when there was no cue. A valid cue has been shown to enhance change detection relative to no cue, and an invalid cue impedes change detection in both auditory (Backer & Alain, 2012; Eramudugolla et al., 2005; Irsik et al., 2016) and visual change detection studies (Rensink, O’Regan, & Clark, 1997). Thus, if a change-relevant object fell outside of a participant’s attentional scope, successfully detecting the change was much less likely. Encouraging a broad scope of attention has been shown to be most advantageous as it extends the number of objects that can be maintained simultaneously (Irsik et al., 2016; Nieuwenstein & Potter, 2006).

Encoding failures can also occur due to a limited memory system, although the extent of the memory limitation is different for vision than audition. For example, another leading cause of change blindness is that visual memory resources have a limited capacity if there is a delay interval between visual scenes, though whether this reflects an object-limit (e.g., Awh, Barton, & Vogel, 2007; Luck & Vogel, 1997; Zhang & Luck, 2008) or an information-limit (e.g., Eng, Chen, & Jiang, 2005; Wilken & Ma, 2004) is still unclear (see Brady, Konkle, & Alvarez, 2011 for a discussion). If there is no delay interval or the interval is very short (e.g., less than 100 ms) detecting a visual change is nearly effortless due to a high-capacity limit of iconic memory (Phillips & Singer, 1974; Rensink et al., 1997; Stelmach, Bourassa, & DiLollo, 1984). Once the delay interval increases a capacity limit ensures (Alvarez & Cavanagh, 2004; Luck & Vogel, 1997), with the memory representation becoming increasingly volatile as the delay interval increases further (Becker, Pashler, & Anstis, 2000). On the other hand, auditory memory is capacity limited even at very short delay intervals (Demany, Trost, Serman, & Semal, 2008; Gregg & Samuel, 2008; Eramudugolla et al., 2005). However, successfully encoded items can be held in memory over much longer intervals that reach several seconds (Gregg, Irsik, & Snyder, 2017). Thus, visual memory appears to be highly accurate if iconic memory can be utilized, while auditory memory is less accurate but more stable over time.

While there have been substantial efforts to identify root causes of change blindness and change deafness, efforts to ameliorate either phenomenon by training have been few. Visual change detection appears amenable to both formal and informal training; however, any enhanced detection ability may be specific to the content that an individual experienced during training. For instance, individuals with training in veterinary medicine (Beck, Martin, Smitherman, & Gaschen, 2013) or with sports expertise (Werner & Thies, 2000) showed enhanced change detection relative to non-experts when the visual scenes contained material related to a participant's training. Master chess players also show an enhanced visual span when observing a chess board (i.e., make fewer fixations) compared to intermediate and novice players, as long as the chess pieces fit a structured chess configuration and were not randomly placed on the board (Reingold, Charness, Pomplun, & Stampe, 2001).

There is one study to our knowledge that has examined formal training to reduce change blindness in a controlled laboratory setting. Gaspar and colleagues (2013) used an adaptive one-shot training design that was intended to reduce the time participants needed to encode visual objects. Thus, enhanced change detection in this context was faster encoding. During training, the duration of the first image in each change detection trial was increased and decreased adaptively as a function of accuracy (target performance: 75% accuracy). Over the course of sixteen training sessions, participants showed a substantial reduction in their encoding time. One limitation of this design is that the training did not provide feedback or a useful strategy that may help improve participant's encoding speed. Although learning can occur without providing error feedback (Beste & Dinse, 2013; Gilbert, 1994), the efficacy and speed at which learning is observable is impacted by the training regimen design (Karni & Bertini, 1997). Thus, it may be possible to enhance change detection ability further and more quickly if participants received helpful feedback on their performance.

Change deafness has not been systematically examined in a laboratory training context, although there is evidence that the auditory system is also malleable during formal and informal training. Musicians can develop listening expertise by undergoing specialized training that often spans many years. Further, there is substantial evidence that musical training enhances auditory processing more generally. For example, musicians excel at concurrent sound segregation (Zendel & Alain, 2009), speech-in-noise perception (Parbery-Clark, Skoe, Lam, & Kraus, 2009), speech-on-speech perception (Başkent & Gaudrain, 2016), and pitch discrimination (Besson, Schön, Moreno, Santos, & Magne, 2007; Tervaniemi, Just, Koelsch, Widmann, & Schröger, 2005). Non-musician listeners have also been shown to improve auditory perception over shorter timescales, such as when training to improve speech perception (Sebastian-Galles, Dupoux, Costa, & Mehler, 2000; Van Engen, 2012) or frequency discrimination (Demany, 1985). It is also possible to improve auditory perceptual abilities informally through long-term exposure. For example, listeners that have been exposed to deaf speech for a year or longer are more accurate than inexperienced listeners when transcribing sentences spoken by deaf individuals (McGarr, 1983; Klimacka, Patterson, & Patterson, 2001).

Taken together, it seems likely that change deafness could be reduced by training, although it is unclear if multiple training sessions are necessary as in Gaspar et al. (2013), or if significant learning could occur after a single training session, especially if helpful feedback is provided. Indeed, the efficacy of a single training session can be underestimated given that learning effects are not always immediately observable. Research on training induced learning has indicated that sensory and motor skills improve over a two-stage process, a fast within-session and a slow between-session learning stage (Karni, 1996; Karni & Sagi, 1993). Fast learning can be induced within the first few minutes of training, and is likely supported by rapid receptive field modification (de Souza, Yehia, Sato, & Callan, 2013; Kapadia et al., 1994). On the other hand, slow learning is not observable until several hours after training, and is supported by more durable, structural changes in the cortex (Atienza, Cantero, & Dominguez-Marin, 2002). In fact, improvement due to slow learning can be observed several years after training occurred (Karni & Sagi, 1993). Different training regimens have also been shown to specifically induce either fast or slow learning (Garcia, Kuai, & Kourtzi, 2013), respectively, such as by providing additional within-session practice or by adjusting task difficulty to avoid floor effects (Karni &

Bertini, 1997; Wright & Sabin, 2007). In sum, the full effect of a training session is dependent on the training regimen and may not be immediately observable, and the presence of slow learning may indicate semi-permanent modification of sensory processes.

In the current study, we addressed whether a) change deafness could be reduced by training, b) whether receiving feedback enhances change detection over training without feedback, and c) whether change detection ability improves over a shorter (fast learning) or longer timescale (slow learning). Four different training activities were used which either involved training and receiving detailed feedback after each response, training without receiving feedback, or no training at all. Detailed feedback was designed to motivate participants to improve their scene segregation ability, and also re-directed participants' attention in the direction of a missed change. We examined performance before training (pre-test), immediately after training (post-test 1), and again twelve hours after testing began (post-test 2). We anticipated that receiving feedback would result in the largest improvement in change detection ability due to our expectation that it would induce enhanced segregation and encoding. However, if learning through simply testing (i.e., testing effects) is sufficient to achieve similar scene perception skills, then the remaining groups may also show improvement. Finally, we anticipated that our training session would induce short-term and more durable long-term learning.

Method

Participants

Sixty-seven undergraduates were recruited from the University of Nevada, Las Vegas subject pool for this experiment (49 females and 18 males; mean age= 20.48, SD= 3.64). All listeners reported having no hearing loss, neurological, or psychiatric disorders and were naïve to the predictions of the study. Course credit was assigned for compensation. All participants provided informed consent according to a protocol approved by a UNLV Institutional Review Board. Data from seven participants were not included in data analyses either due to attrition after session 1 (n= 5) or because they pushed random buttons during the study (n=2). Consequently, the results are reported for the remaining 60 listeners.

Apparatus

Sounds were presented through Sennheiser HD 280 headphones at approximately 70 dB SPL. The experiment was run using Presentation® software (Version 17.0, Neurobehavioral Systems, Inc., Berkeley, CA, www.neurobs.com) on a PC running Windows 7.

Stimuli

15 band-pass filtered noise rhythms were used to create auditory scenes for the experiment. These sounds have been used previously (Gregg et al., 2017), and were created using parameters inspired by Puschmann et al. (2013). Each individual noise rhythm has a total duration of 1000 ms and contains a series of noise bursts that are either short (1/48 s), medium (1/24 s), or long (1/12 s) in duration. Perception of a faster or slower rhythm was induced by inserting intervals of silence between each burst that are also either short (1/48 s), medium (1/24 s), or long (1/12 s) in duration. Noise bands for each rhythm have a center frequency of 200, 400, 800, 1600, 3200 Hz, or 6400 Hz, with bandwidths set to 25% of the center frequency. Thus, each noise rhythm contains a unique noise burst duration, silent interval, center frequency, and frequency bandwidth. Using a custom MATLAB script, the 15 noise rhythms were combined to create 700 auditory scenes, each which contained 6 individual noise rhythms with simultaneous onsets.

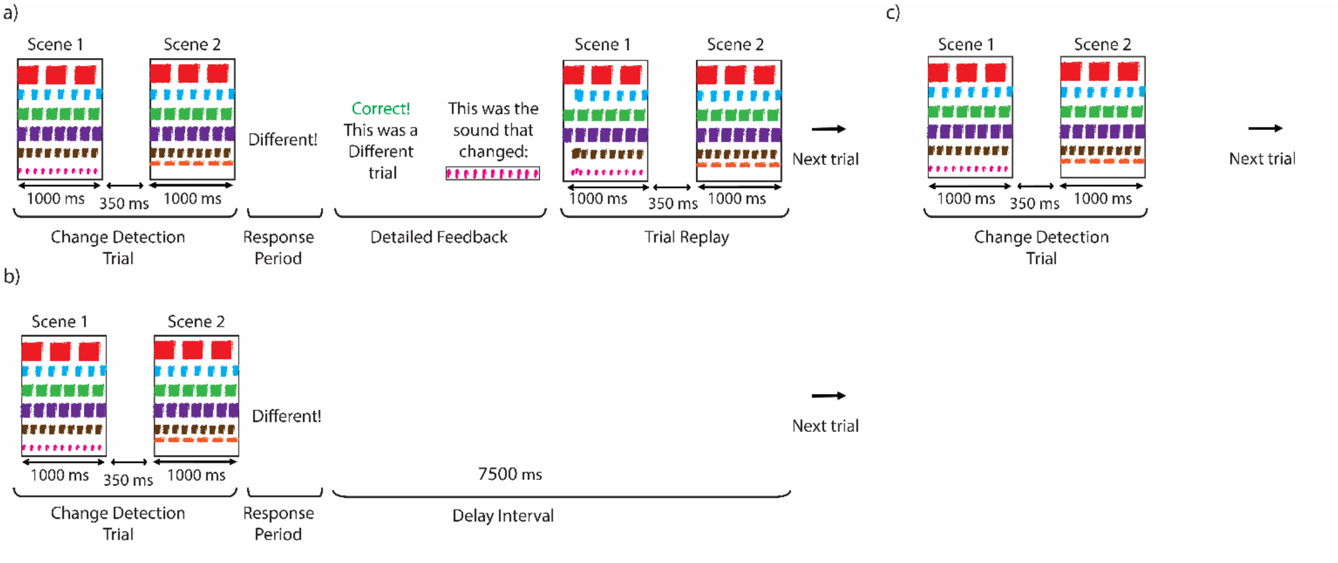
Procedure

Each listener completed change detection trials during two experimental sessions that occurred within a twelve-hour period. During a trial, participants heard two auditory scenes (i.e., scene 1 followed by scene 2) separated by a 350 ms silent interval. The sounds in scene 2 were either identical to those in scene 1 (same trial), or contained five noise rhythms from scene 1 and one new noise rhythm (different trial). The task was to indicate by button press whether scene 1 and scene 2 were the "same" or "different". An unequal proportion of same and different trials were purposely used to allow the study to be converted to an event-related brain potential paradigm in a subsequent experiment. This practice has been used previously and has not been reported to result in excessive bias to report the presence of a change (see Snyder & Gregg, 2012; Gregg, Irsik, & Snyder, 2014).

During the first session (8:00 a.m. start time), all listeners completed a pre-test (150 trials: 112 different, 38 same), a training activity (250 trials: 188 different, 62 same), and an immediate post-test (150 trials: 112 different, 38 same). During the second session (8:00 p.m. start time), all listeners returned to the laboratory to complete a second post-test (150 trials: 112 different, 38 same). To assess the relative efficacy of a training type, listeners were assigned to one of four possible training activities. One group practiced change detection by completing trials and receiving detailed feedback on their performance (detailed feedback group). Detailed feedback during different trials indicated whether a response was correct or incorrect and identified the trial type (e.g., Correct! This was a different trial). Next, the individual sound that changed from scene 1 was presented, after which both scene 1 and scene 2 were replayed before a new trial would begin (Figure 12a). The detailed feedback during same trials was identical except for the replay of a change-relevant sound from scene 1. Instead, a message would appear on the screen which said, “There was no changed sound”.

A second group also completed change detection trials during the training activity but did not receive any feedback on their performance. To ensure that these participants would spend a comparable amount of time completing the task, the trials were spaced to occur at the same time points as the detailed feedback group, resulting in a long inter-trial-interval (ITI) (no feedback long ITI group, see Figure 12b). A third group also completed change detection trials without feedback, but each trial began after a response was recorded, resulting in a short ITI (no feedback short ITI group, see Figure 12c). Finally, a fourth group watched a documentary instead of practicing change detection (control group). Task length for this group was controlled to equal the time needed to complete the training task for the detailed feedback or no feedback long ITI groups (approximately 45 minutes).

Figure 12. Trial schematic during training activity for the (a) detailed feedback, (b) no feedback long ITI, and (c) no feedback short ITI groups.



Data Analysis

Participant responses were used to calculate the proportion of hits (responding "Different" on *different* trials) and false alarms (responding "Different" on *same* trials). Any proportions of either 0 or 1 for false alarms or hits were adjusted to prevent infinite values by replacing 0 and 1 with 1/(2N) and 1-1/(2N) respectively, where N equals the total number of trials on which a proportion was based (Macmillan & Kaplan, 1985). Adjusted hit and false alarm rates were submitted to R software (version 3.4.0) to obtain d′ using the differencing strategy (see Appendix A5.4 in Macmillan & Creelman, 2005). To quantify participant response bias, we also calculated c by multiplying the sum of each z-transformed false alarm and hit rate by -.5 (e.g., -.5*(zHit + zFA)). Negative values of c indicate a bias to respond 'yes, there was a change', while a positive value indicates a bias to respond 'no, there was no change'. d′ and c scores were examined during the training activity and tests by using separate two-way ANOVAs. Participant responses were also broken down by experimental block to examine how each group progressed through the training and tests. The training activity contained more trials than the tests, which resulted in additional experimental blocks for analysis. Thus, training activity type (detailed feedback, no feedback long ITI, no feedback short ITI) was the between-subjects factor and block (block 1, block 2, block 3, block 4) was the within-subject factor for the training analysis. For the test data, training activity type (detailed feedback, no feedback long ITI, no feedback short ITI, control group) was the between-subjects factor, while test (pretest, post-test 1, post-test 2) and block (block 1, block 2) were the within-subjects factors. All pair-wise comparisons were performed using the Least Significant Differences correction.

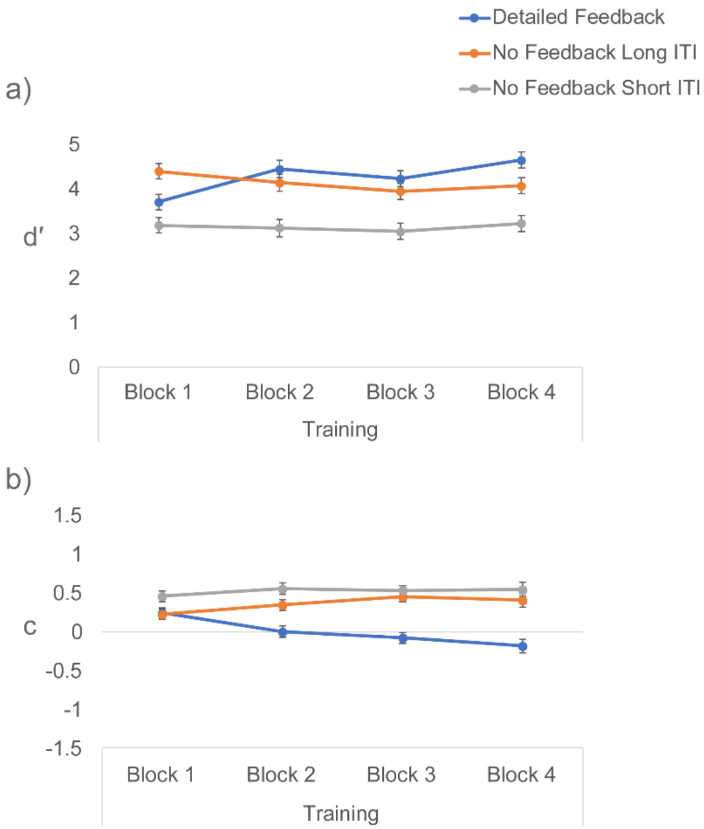
Results

Training Activity

For the analysis of d′, there was a significant effect of training activity type, $F(2, 42) = 16.34$, $p < .001$, $\eta^2_p = .44$, and a significant effect of block, $F(3, 126) = 2.90$, $p = .038$, $\eta^2_p = .07$. As can be seen in figure 13a, the group differences are driven largely by better performance of the detailed feedback and the no feedback long ITI groups relative to the no feedback short ITI group (p's <.001). A significant training activity type x block interaction was found, $F(6, 126) = 6.13$, $p < .001$, $\eta^2_p = .23$. We conducted separate one-way ANOVAs to investigate the interaction, and found three separate patterns of change. The detailed feedback group showed a linear *increase* in d′, $F(1, 14) = 18.13$, $p = .001$, $\eta^2_p = .56$, while the no feedback long ITI group showed a trend-level linear *decrease* in d′, $F(1, 14) = 4.51$, $p = .052$, $\eta^2_p = .24$, and no change in d′ for the no feedback short ITI group (p=.917).

For the analysis of c, similar findings were observed. A significant effect of training activity type was found, $F(2, 42) = 19.26$, $p < .001$, $\eta^2_p = .48$. This indicated an overall difference in response bias between the detailed feedback group and the no feedback groups, with the detailed feedback group employing a response strategy that was overall more neutral (i.e., c score is near zero) while the no feedback groups retained an overall bias to respond ‘no’ (figure 13b). Next, a significant training activity type x block interaction was found, $F(6, 126) = 9.37$, $p < .001$, $\eta^2_p = .31$. Three separate one-way ANOVAs were conducted and revealed a complementary pattern with the findings for d′. The detailed feedback group showed a linear decrease in c, $F(1, 14) = 32.92$, $p < .001$, $\eta^2_p = .70$, which indicated their response strategy moved from somewhat biased to respond ‘no’ to slightly biased towards ‘yes’. The no feedback long ITI group showed a linear increase in c, $F(1, 14) = 7.74$, $p =< .015$, $\eta^2_p = .36$, which indicated their bias changed more strongly towards ‘no’. Finally, the no feedback short ITI group’s response bias did not significantly change (p=.247).

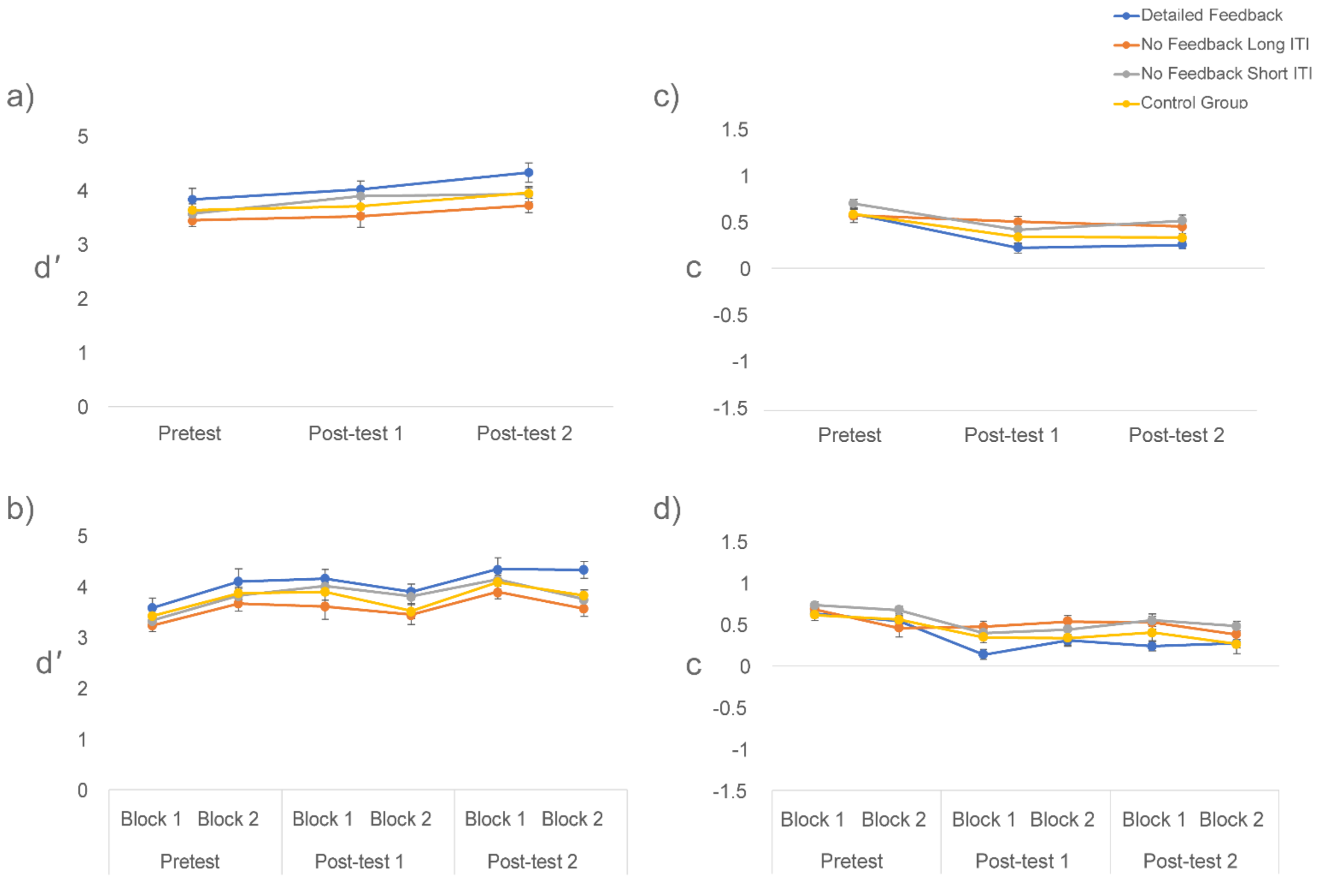
Figure 13. Change detection performance shown during the training activity. Performance is measured by a) d′ (sensitivity), and b) c (response bias). Error bars represent standard error.



Test Performance

For the analysis of d′, there was a significant linear effect of test, $F(1, 56) = 50.81$, $p < .001$, $\eta^2_p = .48$, which indicated that d′ increased linearly from pre-test to post-test 2 (see Figure 14a). The between-subjects effect of training activity type did not reach significance ($p = .071$). Together, this indicates that performance did significantly improve, and that group differences were minor when performance across the three tests were collapsed together. The effect of block was also not significant, but there was a significant test x block interaction, $F(2, 112)= 30.35$, $p < .001$, $\eta^2_p = .35$. As can be seen in Figure 14b, performance during the pretest improved from block 1 to block 2, however, during post-test 1 and post-test 2 an opposite trend occurred. This effect was similar between groups, except during post-test 2 for the detailed feedback which showed stable performance across blocks.

Figure 14. Change detection performance during the pre-test, post-test 1, and post-test 2. Overall performance for each test is shown in a) measured by d′ and in b) measured by c. Performance is shown by block in c) d′ by block, and d) c by block. Error bars represent standard error.



For the analysis of c, response bias also changed linearly from pre-test to post-test 2, *F*(1, 56) = 52.89, $p < .001$, $\eta^2_p = .49$, and the effect of training activity type was again not significant ($p = .085$). Thus, response bias for all groups changed from a tendency to respond ‘no’ towards a bias to respond ‘yes’ (Figure 14c). A significant training activity type x test interaction, *F*(6, 112) = 2.63, $p = .02$, $\eta^2_p = .12$, and a training activity type x block interaction were both found, *F*(3, 56) = 3.63, $p = .018$, $\eta^2_p = .16$. Together, this showed that certain training groups had a different trajectory in the change of response bias across tests and experimental blocks (Figure 14d). Test performance for each training group was subsequently examined separately to further explore the significant interactions for c, and to observe any unique changes in d′ that are specific to a training style.

Detailed feedback group. Participants who received detailed feedback showed a linear increase in d′ from pre-test to post-test 2 (see Table 6 for a summary of mean differences), $F(1,14) = 21.70$, $p < .001$, $\eta^2_p = .61$, suggesting that change deafness was significantly reduced. Although mean d′ had increased during training (see Figure 13a), participants were not able to fully retain this improvement at post-test 1 (pretest vs. post-test 1, p=.288). While d′ moderately increased from post-test 1 to post-test 2 (p=.06, n.s.), significant test improvement was only observed when comparing the pre-test to post-test 2 ($p < .001$), suggesting gradual improvement. Finally, a significant test x block interaction was found, $F(2, 28) = 5.61$, $p = .009$, $\eta^2_p = .29$. This showed that performance increased across blocks during the pre-test, decreased across blocks during post-test 1, and remained stable during the blocks in post-test 2 (Figure 14b).

As for c, there was a significant linear decline, $F(1,14) = 47.18$, $p < .001$, $\eta^2_p = .77$, with much of the trend driven by a steep drop in c at post-test 1 (p<.001; see Table 1). This indicates that participants changed from a bias to respond ‘no’ towards ‘yes, there was a change’ from the pretest to post-test 1. A test x block interaction was also found, $F(2, 28) = 4.92$, $p = .015$, $\eta^2_p = .26$, as was found with d′. Comparing the trajectory of d′ and c within each test revealed that detection sensitivity often increased when participant response bias became more liberal, and decreased as response bias became more conservative. For example, d′ increased when c decreased during the pre-test, d′ decreased when c increased during post-test 1, and both d′ and c remained stable during post-test 2 (compare figures 14b and 14d). However, the significant change in c between the pre-test and post-test 1 did not occur with an equivalent increase in d′ (compare figures 14a and 14c). This suggests that the response strategy used during post-test 1 was motivated by additional factors beyond stimulus information. At post-test 2, a final adjustment of c occurred with a significant increase in sensitivity. Taken together, receiving detailed feedback during training had a significant and positive impact on change detection accuracy. Further, the trajectory of improvement also suggests that the learning induced here was largely dependent on a slower consolidation process that occurred over a longer timescale.

No feedback long ITI group. Next, participants that trained without feedback and had long ITIs showed a significant linear increase in d′ from pre-test to post-test 2, *F*(1, 14) = 6.36, *p*= .024, η^2_p = .31. Performance increased rather gradually, with significant improvement observed only at post-test 2 relative to the pre-test (*p*=.024). A significant test x block interaction was also found, *F*(2, 28) = 6.18, *p*= .006, η^2_p = .31, which revealed that performance tended to decrease during experimental blocks during the post-tests, but increased during the pre-test (see Figure 14b). As for the analysis of c, response bias did not change significantly as a function of test (*p*=.162), although a test x block interaction, *F*(2, 28) = 4.23, *p*= .023, η^2_p = .24, showed that the trajectory of c during experimental blocks was in different directions during the pre-test and post-test 2. While the no feedback long ITI group did not make as large of an adjustment to c as the detailed feedback group, comparing the trajectory of d′ and c also showed that d′ changed predictably with c. Thus, learning to improve change detection is also possible by simply testing without feedback. The long ITIs during training also seem to have induced a consolidation process comparable to the detailed feedback participants.

No feedback short ITI group. Participants that tested without feedback and had short ITIs during training showed a significant linear increase in d′, *F*(1, 14) = 16.36, *p* = .001, η^2_p = .54, suggesting that change deafness was substantively reduced. d′ improved from pre-test to post-test 1 (*p*=.012), and overall (*p* = .001), but the increase in d′ from post-test 1 to post-test 2 was not large enough to be significant (*p*=.642). Response bias also changed linearly across tests, *F*(1, 14) = 15.47, *p* = .002 η^2_p = .53, with a reduction in c at post-test 1 (*p* = .001), and a smaller non-significant increase in c at post-test 2 (*p* = .067). Taken together, participants that did not receive detailed feedback and had short ITIs were able to improve their change detection ability simply by testing, and to a greater extent than those that had long ITIs between trials during training. The change in response strategy appears to be driven by greater sensitivity to changes, as indicated by an increase in d′ when a more liberal response strategy towards ‘yes’ was adopted. In contrast to the previous two groups, majority of the improvement was observed immediately at post-test 1. Therefore, participants in the short ITI group seem to have had access mainly to a fast learning mechanism.

Control group. The control group also showed a significant linear increase in d′ across tests, *F*(1, 14) = 9.92, *p* = .007, η^2_p = .42. Participants showed a small non-significant increase in d′ from pre-test to post-test 1 (*p*=.624), a substantial increase from post-test 1 to post-test 2 (*p*=.037) and overall from pretest to post-test 2 (*p*=.007). c declined linearly across tests, *F*(1, 14) = 16.31, *p* = .001, η^2_p = .54, with a significant drop in c from pre-test to post-test 1 (p<.001), and overall (*p* = .001). Thus, listeners in the control group were able to learn from a combination of testing (i.e., during the pre-test and post-test 1) and taking a break during the first experimental session, but this improvement was not observable until post-test 2. Response bias shift was also substantially adjusted towards yes, but this did not immediately coincide with an increase in d′.

Table 6. Summary of Group Mean Difference Scores for d′ (sensitivity) and c (response bias).

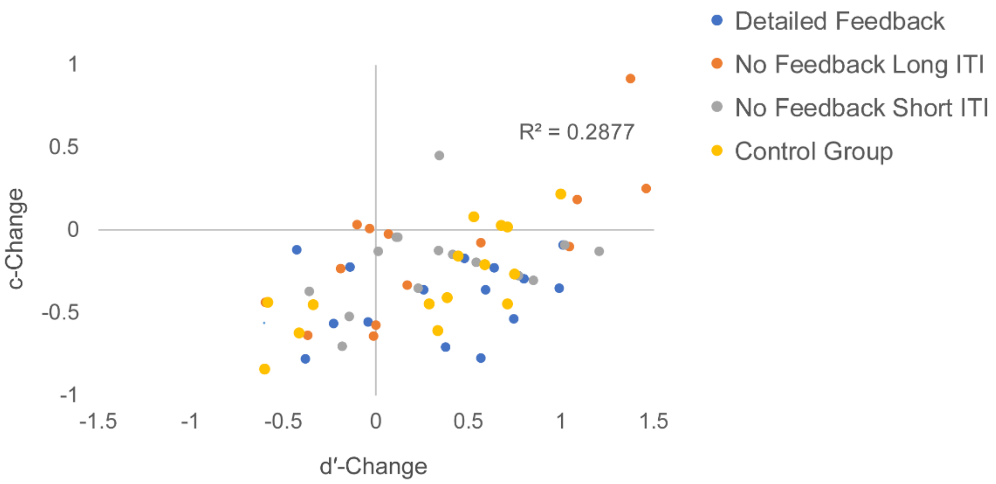
	d′ Change			c Change		
Training Group	Post 1-Pre	Post 2-Post 1	Post 2-Pre	Post 1-Pre	Post 2-Post 1	Post 2-Pre
Detailed Feedback	+0.19	+0.31	+0.50***	-0.36***	+0.03	-0.33***
No Feedback Long ITI	+0.08	+0.20	+0.28*	-0.07	-0.05	-0.12
No Feedback Short ITI	+0.33*	+0.04	+0.37*	-0.28**	+0.10	-0.19**
Control Group	+0.07	+0.25*	+0.31**	-0.24***	-0.01	-0.25**

Note. Asterisks indicate a significant change between tests. *p<.05. ** p<.01. ***p<.001.

Learning and Response Bias

One consistent finding among groups was a trade-off observed between d′ and c. More specifically, three out of the four groups showed a substantial reduction in c at post-test 1 that was not accompanied by an increase in change sensitivity. However, higher d′ followed as certain groups re-adjusted their response strategy at post-test 2. Thus, there may be an optimal range that response bias can be adjusted to achieve better change detection performance. Accordingly, the relationship between the amount of learning (d′-change) and the size of the response bias shift (c-change) from the pre-test to post-test 2 was examined. Since all participants began with larger positive c values, making a large adjustment to response bias after the pre-test would result in a negative c-change value, while a modest to small adjustment would result in either a near-zero or positive c-change value. For d′, a larger positive d′-change value indicates that d′ increased from the pre-test to post-test 2, while a small or negative d′-change value indicates modest to no improvement. There was a significant positive correlation between d′-change and c-change, r(60)=.54, *p*<.001 (see Figure 15). Thus, participants that made a large adjustment towards a ‘yes’ bias (i.e., larger negative c-change value) showed less improvement in d′ at post-test 2 (i.e., larger negative d′-change score). Modest to small adjustments of c (i.e., positive c-change values or c-change closer to 0) were associated with greater improvement at the task (i.e., larger positive d’-change values).

Figure 15. Scatterplot showing the correlation between the amount of learning (d′-change) and response bias change (c-change)



Discussion

Our first major finding is that there are multiple training options to improve auditory change detection which can be executed within a single training session. However, the size of improvement was not equal between participant groups. Training and receiving detailed feedback was the most effective strategy for reducing change deafness, as indicated by the largest increase in d′ among the four groups (d′ increase +0.50). The remaining groups were also able to improve through simply testing, although the magnitude of improvement was dependent on the amount of practice and the timespan during which practice occurred. For example, the no feedback short ITI group received the same amount of practice as the no feedback long ITI group, but it occurred over a much shorter timescale. Accordingly, the short ITI group showed substantially more improvement than the long ITI group (see Table 1), and only trailed behind the detailed feedback group's improvement by -0.13 d′. This is consistent with prior work on training-independent learning (Beste & Dinse, 2013), which suggests that task learning can occur if a high level of sensory stimulation occurs during a short time period.

The control group also showed a remarkable amount of learning on the task (see Table 1), despite not participating in change detection practice during the training activity. In fact, the data suggest that taking a break during the control activity benefited performance; perhaps by allowing short-term consolidation to occur. This is consistent with Gottselig et al. (2004) who reported learning when participants took a short break after training, although a short nap was most effective in consolidating task-related memory. In contrast, Little and colleagues (2017) reported that taking a thirty-minute break halfway through each training session resulted in no improvement on a frequency discrimination task, and suggested that the break interrupted a necessary integration process for learning. However, multiple days of extensive training were needed to show improvement in the Little et al. (2017) experiment, while participants showed learning following one training session in the current study and Gottselig et al. (2004). Therefore, whether a break impedes learning may be dependent on the difficulty at which listeners receive positive benefits of training.

The presence of fast or slow learning was also dependent on the timespan during which training occurred. For example, the no feedback short ITI group completed a substantial amount of practice over a much shorter time span than the other three groups. Significant task-learning for this group was observed at the first post-test, with very little improvement thereafter. The remaining groups showed much less improvement at post-test 1, but continued to show improvement at post-test 2. Therefore, a shorter duration practice session primarily induced fast learning, while a longer duration session induced both fast and slow learning. These findings underscore the utility of obtaining post-training performance at multiple time points, as well as the importance of distinguishing between the type of learning that a practice session induces. If performance had not been examined at a second time point after training, the effect of both training with and without detailed feedback (e.g., no feedback long ITI and control group) would have been significantly underestimated or missed entirely.

Participant response strategy (measured by c) changed substantially throughout the experiment, especially for the detailed feedback group. However, changes in c did not always coincide with a change in d′, particularly at post-test 1. One explanation is that participants may have employed a chosen response strategy inconsistently, perhaps due to difficult trials where uncertainty was high. Another option is that participants' response criterion may have been motivated by factors beyond stimulus information. A major hallmark of both change deafness and change blindness is that participants have subpar change detection abilities, but are not aware of their low accuracy. In the current study, the detailed feedback group made the largest response strategy adjustment following training, and were the only group that had any knowledge of their change detection accuracy during the study. Accordingly, the detailed feedback group's response strategy may have been impacted by knowledge of how often they missed changes, resulting in a liberal response bias during instances of high uncertainty. Importantly, an undifferentiated liberal response strategy would result in lower d′ scores due to an inflated false alarm rate. This is consistent with the detailed feedback group's performance during post-test 1, but this issue appears resolved at post-test 2 as c was adjusted and d′ increased. Irrespective of group, we found an optimal range to adjust c that coincided with an increase in d′ (Figure 15). A large response strategy adjustment tended to result in less improvement on the task, while a modest adjustment to response strategy was associated with more learning (i.e., increased d′). Therefore, adopting too liberal of a response bias impacted d′ negatively, likely due to an increase in false alarms.

In conclusion, our findings indicate that change deafness can be reduced quite efficiently if listeners receive helpful feedback on their performance or if a high level of practice is completed in a short time period. This is an important finding since it suggests that the conditions needed to improve auditory change detection are quite flexible. This was especially evident in the control group, which showed substantial learning under conditions that were not expected to impact performance. We were not able to entirely extinguish change deafness for any group. Additional training may be useful in trying to fully eliminate change deafness, although it is not necessary to substantially impact auditory change detection.

Chapter 7: Concluding Discussion

The content from three separate manuscripts was presented, each which utilized a novel design to address a different question about change deafness. While much of this paper has discussed underlying causes, the final manuscript takes an applied perspective by attempting to improve auditory processing and change detection. Together, the findings from each study have made a substantial contribution to change deafness research, and made several important comparisons between the auditory and visual domain.

Nevertheless, there are still unanswered questions that are worth discussing. For example, the major takeaways from the first manuscript (Chapter 2) were that auditory objects that are outside the focus of attention are not fully encoded and that a global attentional strategy is most advantageous. The latter finding has important implications for training, as this may be a viable approach for improving change detection. However, it may be more beneficial to either adopt a broad attentional scope towards the entire scene consisting of multiple objects, or instead toward the global acoustic properties of an auditory scene, without forming a representation of individual objects. Future studies should determine whether either attentional strategy can be induced via training, and which attentional level is most effective for change detection. A similar assertion can be said of the second manuscript (Chapter 4), at least in regard to the finding regarding memory capacity. That is, change detection during all sound types was negatively impacted by scene size, indicating that change deafness is at least partly caused by a limited auditory memory capacity. Therefore, future studies could focus on increasing memory capacity during training to reduce change deafness.

Other major questions are in regard to the final manuscript (Chapter 6), which showed that change deafness could be reduced via training with feedback or practice. Given that listeners were only tested on the same day as training, it is not possible to determine whether the observed learning was long-lasting. Future studies should address whether enhanced performance is still observable several weeks following training. If the effects of a single session fade, it may be necessary to use multiple sessions to ensure long-lasting results. In addition, it would also be useful to examine whether any additional learning is observed following a night of sleep. The positive effect of sleep on learning is well established (e.g., Diekelmann, Wilhelm, & Born, 2009; Stickgold & Walker, 2007), and can even occur following a brief nap (Mednick et al., 2002; Mednick, Nakayama, & Stickgold, 2003). There are also some paradigms which depend on sleep to observe the full effect of training (Fenn, Nusbaum, & Margoliash, 2003). Future studies could also examine whether an additional benefit of sleep is observed when training to reduce change deafness, and whether the size of the benefit is different for various training interventions.

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Appendix III: IRB Approval 2013

UNLV
UNIVERSITY OF NEVADA LAS VEGAS

Social/Behavioral IRB – Expedited Review Continuing Review Approved

NOTICE TO ALL RESEARCHERS:

Please be aware that a protocol violation (e.g., failure to submit a modification for any change) of an IRB approved protocol may result in mandatory remedial education, additional audits, re-consenting subjects, researcher probation, suspension of any research protocol at issue, suspension of additional existing research protocols, invalidation of all research conducted under the research protocol at issue, and further appropriate consequences as determined by the IRB and the Institutional Officer.

DATE: November 20, 2013

TO: **Dr. Joel Snyder**, Psychology

FROM: Office of Research Integrity – Human Subjects

RE: Notification of IRB Action
Protocol Title: **Neural Mechanisms of Auditory and Visual Processing in Healthy Adults**
Protocol #: 0710-2518
Expiration Date: November 19, 2014

Continuing review of the protocol named above has been reviewed and approved.

This IRB action will reset your expiration date for this protocol. The protocol is approved for a period of one year from the date of IRB approval. The new expiration date for this protocol is November 20, 2013. If the above-referenced project has not been completed by this date you must request renewal by submitting a Continuing Review Request form 30 days before the expiration date.

PLEASE NOTE:
Upon approval, the research team is responsible for conducting the research as stated in the protocol most recently reviewed and approved by the IRB, **which shall include using the most recently approved Informed Consent/Assent forms** and recruitment materials. The official versions of these forms are indicated by footer which contains current approval and expiration dates.

Should there be *any* change to the protocol, it will be necessary to submit a **Modification Form** through ORI - Human Subjects. No changes may be made to the existing protocol until modifications have been approved by the IRB. Modified versions of protocol materials must be used upon review and approval. Unanticipated problems, deviations to protocols, and adverse events must be reported to the ORI – HS within 10 days of occurrence.

If you have questions or require any assistance, please contact the Office of Research Integrity - Human Subjects at IRB@unlv.edu or call 895-2794.

Appendix IV: IRB Approval 2014

UNLV

Social/Behavioral IRB – Expedited Review Continuing Review Approved

NOTICE TO ALL RESEARCHERS:

Please be aware that a protocol violation (e.g., failure to submit a modification for any change) of an IRB approved protocol may result in mandatory remedial education, additional audits, re-consenting subjects, researcher probation, suspension of any research protocol at issue, suspension of additional existing research protocols, invalidation of all research conducted under the research protocol at issue, and further appropriate consequences as determined by the IRB and the Institutional Officer.

DATE: October 29, 2014

TO: **Dr. Joel Snyder**, Psychology

FROM: Office of Research Integrity – Human Subjects

RE: Notification of IRB Action
Protocol Title: Neural Mechanisms of Auditory and Visual Processing in Healthy Adults

Protocol #: 0710-2518

Expiration Date: October 28, 2015

Continuing review of the protocol named above has been reviewed and approved.

This IRB action will reset your expiration date for this protocol. The protocol is approved for a period of one year from the date of IRB approval. The new expiration date for this protocol is October 28, 2015. If the above-referenced project has not been completed by this date you must request renewal by submitting a Continuing Review Request form 30 days before the expiration date.

PLEASE NOTE:

Upon approval, the research team is responsible for conducting the research as stated in the protocol most recently reviewed and approved by the IRB, which shall include using the most recently submitted Informed Consent/Assent forms and recruitment materials. The official versions of these forms are indicated by footer which contains current approval and expiration dates.

Should there be *any* change to the protocol, it will be necessary to submit a **Modification Form** through ORI - Human Subjects. No changes may be made to the existing protocol until modifications have been approved by the IRB. Modified versions of protocol materials must be used upon review and approval. Unanticipated problems, deviations to protocols, and adverse events must be reported to the ORI – HS within 10 days of occurrence.

If you have questions or require any assistance, please contact the Office of Research Integrity - Human Subjects at IRB@unlv.edu or call (702) 895-2794.

Appendix V: IRB Approval 2015

UNLV Social/Behavioral IRB - Expedited Review
Continuing Review Approved

DATE: October 26, 2015

TO: Joel Snyder
FROM: UNLV Social/Behavioral IRB

PROTOCOL TITLE: [710883-8] Neural Mechanisms of Auditory and Visual Processing in Healthy Adults
SUBMISSION TYPE: Continuing Review/Progress Report

ACTION: APPROVED
APPROVAL DATE: October 25, 2015
EXPIRATION DATE: October 24, 2016
REVIEW TYPE: Expedited Review

Thank you for submission of Continuing Review/Progress Report materials for this protocol. The UNLV Social/Behavioral IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a protocol design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This IRB action will reset your expiration date for this protocol. The protocol is approved for a period of one year from the date of IRB approval. The new expiration date for this protocol is October 24, 2016.

PLEASE NOTE:
Attached with this approval notice is the **official Informed Consent/Assent (IC/A) Form** for this study. Only copies of this official IC/A form may be used when obtaining consent. Please keep the original for your records.

Should there be *any* change to the protocol, it will be necessary to submit a **Modification Form** through ORI - Human Subjects. No changes may be made to the existing protocol until modifications have been approved.

ALL UNANTICIPATED PROBLEMS involving risk to subjects or others and SERIOUS and

UNEXPECTED adverse events must be reported promptly to this office. Please use the appropriate reporting forms for this procedure. All FDA and sponsor reporting requirements should also be followed.

All NONCOMPLIANCE issues or COMPLAINTS regarding this protocol must be reported promptly to this office.

This protocol has been determined to be a Minimal Risk protocol. Based on the risks, this protocol requires continuing review by this committee on an annual basis. Submission of the **Continuing Review**

Request Form must be received with sufficient time for review and continued approval before the expiration date of October 24, 2016.

If you have questions, please contact the Office of Research Integrity - Human Subjects at IRB@unlv.edu or call 702-895-2794. Please include your protocol title and IRBNet ID in all correspondence.

Appendix VI: IRB Approval 2016

UNLV

UNLV Social/Behavioral IRB - Expedited Review
Continuing Review Approved

DATE: November 2, 2016

TO: Joel Snyder
FROM: UNLV Social/Behavioral IRB

PROTOCOL TITLE: [710883-20] Neural Mechanisms of Auditory and Visual Processing in Healthy Adults
SUBMISSION TYPE: Continuing Review/Progress Report

ACTION: APPROVED
APPROVAL DATE: November 2, 2016
EXPIRATION DATE: November 1, 2017
REVIEW TYPE: Expedited Review

Thank you for submission of Continuing Review/Progress Report materials for this protocol. The UNLV Social/Behavioral IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a protocol design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This IRB action will reset your expiration date for this protocol. The protocol is approved for a period of one year from the date of IRB approval. The new expiration date for this protocol is November 1, 2017.

PLEASE NOTE:
Attached with this approval notice is the **official Informed Consent/Assent (IC/A) Form** for this study. Only copies of this official IC/A form may be used when obtaining consent. Please keep the original for your records.

Should there be *any* change to the protocol, it will be necessary to submit a **Modification Form** through ORI - Human Subjects. No changes may be made to the existing protocol until modifications have been approved.

ALL UNANTICIPATED PROBLEMS involving risk to subjects or others and SERIOUS and UNEXPECTED adverse events must be reported promptly to this office. Please use the appropriate reporting forms for this procedure. All FDA and sponsor reporting requirements should also be followed.

All NONCOMPLIANCE issues or COMPLAINTS regarding this protocol must be reported promptly to this office.

This protocol has been determined to be a Minimal Risk protocol. Based on the risks, this protocol requires continuing review by this committee on an annual basis. Submission of the **Continuing Review Request Form** must be received with sufficient time for review and continued approval before the expiration date of November 1, 2017.

If you have questions, please contact the Office of Research Integrity - Human Subjects at IRB@unlv.edu or call 702-895-2794. Please include your protocol title and IRBNet ID in all correspondence.

Office of Research Integrity - Human Subjects
4505 Maryland Parkway . Box 451047 . Las Vegas, Nevada 89154-
1047 (702) 895-2794 . FAX: (702) 895-0805 . IRB@unlv.edu

Appendix VII: IRB Approval 2017

UNLV

UNLV Social/Behavioral IRB - Expedited Review
Continuing Review Approved

DATE:	November 21, 2017
TO:	Joel Snyder
FROM:	UNLV Social/Behavioral IRB
PROTOCOL TITLE:	[710883-30] Neural Mechanisms of Auditory and Visual Processing in Healthy Adults
SUBMISSION TYPE:	Continuing Review/Progress Report
ACTION:	APPROVED
APPROVAL DATE:	November 15, 2017
EXPIRATION DATE:	November 14, 2018
REVIEW TYPE:	Expedited Review

Thank you for submission of Continuing Review/Progress Report materials for this protocol. The UNLV Social/Behavioral IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a protocol design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This IRB action will reset your expiration date for this protocol. The protocol is approved for a period of one year from the date of IRB approval. The new expiration date for this protocol is November 14, 2018.

PLEASE NOTE:
Attached with this approval notice is the **official Informed Consent/Assent (IC/A) Form** for this study. Only copies of this official IC/A form may be used when obtaining consent. Please keep the original for your records.

Should there be *any* change to the protocol, it will be necessary to submit a **Modification Form** through ORI - Human Subjects. No changes may be made to the existing protocol until modifications have been approved.

ALL UNANTICIPATED PROBLEMS involving risk to subjects or others and SERIOUS and UNEXPECTED adverse events must be reported promptly to this office. Please use the appropriate reporting forms for this procedure. All FDA and sponsor reporting requirements should also be followed.

All NONCOMPLIANCE issues or COMPLAINTS regarding this protocol must be reported promptly to this office.

This protocol has been determined to be a Minimal Risk protocol. Based on the risks, this protocol requires continuing review by this committee on an annual basis. Submission of the **Continuing Review Request Form** must be received with sufficient time for review and continued approval before the expiration date of November 14, 2018.

If you have questions, please contact the Office of Research Integrity - Human Subjects at IRB@unlv.edu or call 702-895-2794. Please include your protocol title and IRBNet ID in all correspondence.

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Appendix VIII: IRB Approval 2018

UNLV

UNLV Social/Behavioral IRB - Expedited Review
Continuing Review Approved

DATE: November 21, 2017

TO: Joel Snyder
FROM: UNLV Social/Behavioral IRB

PROTOCOL TITLE: [710883-30] Neural Mechanisms of Auditory and Visual Processing in Healthy Adults
SUBMISSION TYPE: Continuing Review/Progress Report

ACTION: APPROVED
APPROVAL DATE: November 15, 2017
EXPIRATION DATE: November 14, 2018
REVIEW TYPE: Expedited Review

Thank you for submission of Continuing Review/Progress Report materials for this protocol. The UNLV Social/Behavioral IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a protocol design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This IRB action will reset your expiration date for this protocol. The protocol is approved for a period of one year from the date of IRB approval. The new expiration date for this protocol is November 14, 2018.

PLEASE NOTE:
Attached with this approval notice is the **official Informed Consent/Assent (IC/A) Form** for this study. Only copies of this official IC/A form may be used when obtaining consent. Please keep the original for your records.

Should there be *any* change to the protocol, it will be necessary to submit a **Modification Form** through ORI - Human Subjects. No changes may be made to the existing protocol until modifications have been approved.

ALL UNANTICIPATED PROBLEMS involving risk to subjects or others and SERIOUS and UNEXPECTED adverse events must be reported promptly to this office. Please use the appropriate reporting forms for this procedure. All FDA and sponsor reporting requirements should also be followed.

All NONCOMPLIANCE issues or COMPLAINTS regarding this protocol must be reported promptly to this office.

This protocol has been determined to be a Minimal Risk protocol. Based on the risks, this protocol requires continuing review by this committee on an annual basis. Submission of the **Continuing Review Request Form** must be received with sufficient time for review and continued approval before the expiration date of November 14, 2018.

If you have questions, please contact the Office of Research Integrity - Human Subjects at IRB@unlv.edu or call 702-895-2794. Please include your protocol title and IRBNet ID in all correspondence.

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Gregg, M.K., Irsik, V.C., & Snyder, J.S. (2017). Effects of capacity limits, memory loss, and sound type in change deafness. *Attention, Perception, & Psychophysics*, *79*, 2564–2575. https://doi.org/10.3758/s13414-017-1416-4.

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Zhang, W., & Luck, S.J. (2009). Sudden death and gradual decay in visual working memory. *Psychological Science, 20*(4), 423-428.

Curriculum Vitae

Vanessa Claire Irsik

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Education

2012-Current **Ph.D.**
Scheduled Completion: March 2018
Experimental Psychology, Cognitive Emphasis
University of Nevada, Las Vegas

2015 **Master of Arts**
Psychology, Cognitive Emphasis
University of Nevada, Las Vegas

2012 **Bachelor of Arts**
Major Concentration: Psychology
Magna Cum Laude
University of Nevada, Las Vegas

Academic Appointments

2012-2017 **Graduate Assistant: Research**
Conducted research under the advisement of Dr. Joel Snyder.
Auditory Cognitive Neuroscience Lab
University of Nevada, Las Vegas

2015-2017 **Graduate Assistant: Teaching**
Taught 100-200 level undergraduate Psychology courses.
Department of Psychology
University of Nevada, Las Vegas

2012-2015 **Lab Coordinator**
Coordinated laboratory events/scheduling, managed equipment, and trained undergraduate research assistants.
Auditory Cognitive Neuroscience Lab
University Nevada, Las Vegas

2010-2012 **Undergraduate Research Assistant**
Collected data for various research projects under the advisement of ACNL graduate students, post doc faculty, and Dr. Joel Snyder.
Auditory Cognitive Neuroscience Lab
University of Nevada, Las Vegas

Awards and Scholarships

2016 **Graduate & Professional Student Association Research Forum**
Awarded first place and cash prize for best oral presentation.
University of Nevada, Las Vegas

2015 **Graduate & Professional Student Association Grant, Fall Award**
Awarded travel funding to present research at professional conference.
University of Nevada, Las Vegas

2015 **Psi Chi Annual Undergraduate Research Conference**
First place poster presentation and cash prize awarded to undergraduate mentees.
University of Nevada, Las Vegas

2014 **Center for Human Adaptive Systems and Environments (CHASE)**
Summer School I: The Dynamics of Music and (NSF-funded program)
Awarded entrance to exclusive specialized training program.
UC Merced, Yosemite, California

2014 **Graduate & Professional Student Association Grant, Spring Award**
Awarded travel funding to present research at professional conference.
University of Nevada, Las Vegas

2013 **Graduate Student Travel Award**
Awarded travel funding to present research at professional conference.
Association of Research in Otolaryngology

Professional Activities

Summer 2017 **Dawson College Bound Program**
Volunteer Presenter
Topic: Introduction to electroencephalography (EEG) as a method used to explore auditory cognition at the Auditory Cognitive Neuroscience Laboratory (ACNL).
University of Nevada, Las Vegas

2015-2016 **Psi Chi Honor Society Graduate Liaison**
Served as a graduate mentor to undergraduate students in the Psi Chi Honor Society.
University of Nevada, Las Vegas

Spring 2015 **Responsible Conduct of Research Training**
Advanced training on ethics in human experimental research.
University of Nevada, Las Vegas

Spring 2015 **Brain Awareness Week**

Volunteer presenter on perception.
Calvary Christian Learning Academy, Las Vegas, NV

2014-2015 **Cohort Representative: Experimental Student Committee**
Represented my graduate program cohort at Experimental Student Committee meetings.
University of Nevada, Las Vegas

2014-2015 **Open Science Collaboration for the Reproducibility Project: Psychology**
Invited author and collaborator.

Fall 2014 **Invited Reviewer**
Journal: Brain and Language.

Fall 2014 **Electrophysiology Training: ABR**
Received training in Dr. Howard Nusbaum's research laboratory.
University of Chicago, IL

Spring 2014 **Brain Awareness Week**
Volunteer presenter on perception.
Cashman Middle School, Las Vegas, NV

Poster and Oral Presentations

*Irsik, V.C., Guthrie, T, Snyder, J.S. (2018, February). Neural correlates of training-related improvements during change detection in complex auditory scenes. Poster session presented at the Midwinter Meeting of the Association for Research in Otolaryngology, San Diego, CA.

*Snyder, J.S., Yerkes, B, Irsik, V.C., Vanden Bosch der Nederlanden, C.M. (2016, November). Varieties of attention affect auditory perception of scenes. Oral presentation given at the 5th Joint Meeting of the Acoustical Society of America and Acoustical Society of Japan, Honolulu, HI.

*Irsik, V.C., & Snyder, J. S. (2016, March). Change deafness is reduced but not eliminated by practice. Oral presentation given at the Graduate and Professional Student Association Research Forum, University of Nevada, Las Vegas.

*Irsik, V.C., & Snyder, J. S. (2015, February). Change deafness is reduced but not eliminated by practice. Poster session presented at the Midwinter Meeting of the Association for Research in Otolaryngology, San Diego, CA.

Gregg, M.K., *Irsik, V.C., & Snyder, J.S. (2015, February). Change deafness is due to both capacity limits and memory loss. Poster session presented at the Midwinter Meeting of the Association for Research in Otolaryngology, San Diego, CA.

*Irsik, V.C, & Snyder, J. S. (2015, November). Change deafness is reduced but not eliminated by practice. Poster session presented at the Psychonomic Society's Annual Meeting, Chicago, IL.

*Irsik, V.C. (2015, November). Exploring the role of subcortical processing in change deafness. Oral presentation given at the 2nd Annual Rebel Grad Slam Three Minute Thesis Competition, University of Nevada, Las Vegas.

*Irsik, V.C, Gregg, M.K., & Snyder, J.S. (2015, April). Change deafness for naturalistic sounds is due to capacity limits, not memory loss. Oral presentation given at the Graduate Psychology Research Fair, University of Nevada, Las Vegas.

*Carbajal, B.G., *Morrison, N.B., Irsik, V, Gregg, M.K., & Snyder, J.S. (2015, April). Change deafness for naturalistic sounds is due to capacity limits, not memory loss. Poster session presented at the Psi Chi Annual Research Conference, University of Nevada, Las Vegas.

*Irsik, V.C, Vanden Bosch der Nederlanden, C.M., Gregg, M.K, & Snyder, J.S. (2014, March). Effects of attention on change deafness depend on the task relevance of the attended object. Oral presentation given at the Graduate and Professional Student Association Research Forum, University of Nevada, Las Vegas.

*Irsik, V.C., *Vanden Bosch der Nederlandedn, C.M., Gregg, M.K., & Snyder, J.S. (2014, February). Effects of attention on change deafness depend on the task relevance of the attended object. Co-presented oral presentation given at the Midwinter Meeting of the Association for Research on Otolaryngology, San Diego, CA.

*Irsik, V.C. (2014, January). The effect of sleep on perceptual learning and memory consolidation. Oral presentation given at the Proseminar Spring Colloquium Series, University of Nevada, Las Vegas.

*Irsik, V.C. (2013, May). Perceptual learning and memory consolidation. Oral presentation given at the Proseminar Spring Colloquium Series, University of Nevada, Las Vegas.

*Irsik, V.C., Gregg, M.K., & Snyder, J.S. (2013, February). The role of object perception in change deafness: Behavioral and event-related potential findings. Poster session presented at the Midwinter Meeting of the Association for Research in Otolaryngology, Baltimore, MD.

*Irsik, V.C., Gregg, M.K., & Snyder, J.S. (2012, May). Change deafness with recognizable and unrecognizable sounds. Poster session presented at the Acoustics Meeting, Hong Kong SAR.

Refereed Publications

Gregg, M.K, Irsik, V.C, Snyder, J.S. (2017). Effects of capacity limits, memory loss, and sound type in change deafness. *Attention, Perception, & Psychophysics, 79*(8), 2564-2575.doi: 10.3758/s13414-017-1416-4

Irsik, V.C, Vanden Bosch der Nederlanden, C.M., & Snyder, J.S. (2016). Broad attention to multiple individual objects may facilitate change detection with complex auditory scenes. *Journal of Experimental Psychology: Human Perception, & Performance, 42*(11), 1806-1817. doi.org/10.1037/xhp0000266

Open Science Collaboration. (2015). Estimating the reproducibility of psychological science. *Science, 349*(6251). doi: 10.1126/science.aac4716

Gregg, M.K., Irsik, V.C., Snyder, J.S. (2014). Change deafness and object encoding with recognizable and unrecognizable sounds. *Neuropsychologia, 61*, 19-30. doi: 10.1016/j.neuropsychologia.2014.06.007

Manuscripts Under Review

Irsik, V., & Snyder, J.S. (Under Review). Change deafness can be reduced, but not eliminated, using brief training interventions. *Journal of Experimental Psychology: Applied.*

Teaching Experience

2017 Spring	**Instructor** Psychology 101: An Introduction to Psychology Sections: 1020; 1021
2016 Fall	**Instructor** Psychology 240: Behavioral Research Methods Section: 1005
2016 Fall	**Instructor** Psychology 10: An Introduction to Psychology Sections: 1009;1013
Spring 2016	**Instructor** Psychology 101: An Introduction to Psychology Sections: 1027;1044
Fall 2015	**Instructor** Psychology 101: An Introduction to Psychology Sections: 1040; 1051
Spring 2015	**Guest Lecturer** Psychology 101 Topic: Synaptic Transmission and Neuroanatomy

Spring 2015 **Guest Lecturer**
Psychology 420
Topic: Introduction to EEG as a Research Method

Spring 2014 **Guest Lecturer**
Psychology 101
Topic: Research Methods

Memberships in Professional Societies

2012-Current Association for Psychological Science, Graduate Student Member

2011-Current Association for Research in Otolaryngology, Graduate Student Member