

Spring 2018

The effect of the similarity of events on change deafness

Caroline Cole
James Madison University

Follow this and additional works at: <https://commons.lib.jmu.edu/honors201019>

 Part of the [Cognition and Perception Commons](#), and the [Cognitive Psychology Commons](#)

Recommended Citation

Cole, Caroline, "The effect of the similarity of events on change deafness" (2018). *Senior Honors Projects, 2010-current*. 535.
<https://commons.lib.jmu.edu/honors201019/535>

This Thesis is brought to you for free and open access by the Honors College at JMU Scholarly Commons. It has been accepted for inclusion in Senior Honors Projects, 2010-current by an authorized administrator of JMU Scholarly Commons. For more information, please contact dc_admin@jmu.edu.

The Effect of the Similarity of Events on Change Deafness

An Honors College Project Presented to

the Faculty of the Undergraduate

College of Health and Behavioral Studies

James Madison University

by Caroline I. Cole

Accepted by the faculty of the Department of Psychology, James Madison University, in partial fulfillment of the requirements for the Honors College.

FACULTY COMMITTEE:

HONORS COLLEGE APPROVAL:

Project Advisor: Michael Hall, Ph.D.
Professor, Psychology

Bradley R. Newcomer, Ph.D.,
Dean, Honors College

Reader: Jeffrey Andre, Ph.D.
Professor, Psychology

Reader: Jeff Dyche, Ph.D.
Associate Professor, Psychology

PUBLIC PRESENTATION

This work is accepted for presentation, in part or in full, at JMU Department of Psychology Student Symposium on April 23rd, 2018

Table of Contents

Acknowledgements	3
Abstract	4
Introduction	5
Method	9
Participants	9
Stimuli	10
Procedure	12
Results	13
Discussion	14
References	21
Appendix	
Musical Training and Experience (MUTE) survey	25
Tables	
Table 1: Error Rates for Combinations of Timbre, Pitch, Pattern of Target Movement and Similarity	28
Table 2: Inferential Statistics of Within-Subject Effects	30
Figures	
Figure 1: Summary of correct responses as a function of similarity between the moving target and one distractor	31
Figure 2: Summary of correct responses as a function of the target's starting location	32

Acknowledgments

Above all, I would like to thank Dr. Michael Hall who made every step of this process possible. The amount of time and effort he spent answering my questions and the hours of sleep he lost to ensure progress was being made went above and beyond his role as my advisor. I would also like to thank him for the initial idea and encouragement to take on this project and for shaping the end of my undergraduate career.

I would also like to thank Dr. Jeffrey Andre and Dr. Jeff Dyche for serving as my committee members. Their experience and expertise of this subject helped to broaden my understanding and provide important feedback to strengthen the final product of this thesis.

I am also grateful for my peers and fellow Auditory Perception laboratory members who contributed to the completion of stimuli creation and running participants through the experiment.

Lastly, I would like to thank my friends and family who supported me through the past few semesters – through the chaos, stress, and excitement of it all.

Abstract

Change deafness is a perceptual phenomenon that occurs when an observer fails to rapidly detect an above-threshold change in a sound source. The present research represented an initial investigation into one stimulus factor, the perceived similarity between array events, that potentially gives rise to change deafness to continuously moving target events. Participants ($N=13$) were presented with arrays of three simultaneous tones of inharmonic, synthetic /a/ and /i/ vowels. Each array event had a distinct pitch [low (A_2), middle ($D^{\#}_3$), high (B_4)] and starting location in perceived space on the azimuth (-40° , 0° , $+40^\circ$). Participants were instructed to identify the pitch of the tone that changed with respect to location in perceived space. The target, or changing event, had either a shared a vowel with another distractor, or had a unique vowel relative to the remaining two events. Mean percent correct identification of change was significantly lower when the target event was similar to distractors, indicating frequent incidence of change deafness, and suggesting that change deafness is dependent upon the degree of event similarity.

Keywords: Change deafness, auditory scene analysis, change detection, auditory event perception, similarity effects, audition

The Effect of the Similarity of Events on Change Deafness

Change deafness is a perceptual phenomenon that occurs when an observer fails to detect a change in an auditory stimulus when both the stimulus and change are well above auditory threshold (Dickerson & Gaston, 2014). This is considered to be the auditory equivalent of change blindness, a phenomenon that occurs when an observer fails to notice a change in a visual stimulus (Rensink, 2002); although an object falls on a substantial portion of the retina, it goes unnoticed because attention is focused elsewhere. While change blindness has been considerably studied, research on change deafness is comparatively limited.

Many initial change deafness studies have used either a one-shot or single-trial paradigm (see Pashler, 1998; Simmons, 1996; Levin & Simmons, 1997; Mitroff, Simmons & Levin, 2004). A one-shot paradigm is essentially a same-different task in which a participant indicates whether two stimulus arrays composed of several events are the same or different, or more specifically, whether an event from the initial array changed in the second array (Snyder & Gregg, 2011). In contrast, in a single-trial task a participant indicates when a single important and instant change has been detected in a stimulus (e.g., a radio broadcast excerpt where the voices of sports announcers change; see Neuhoff & Bochtler, 2017). A “slow-change” version of this task also has been implemented, where participants are required to detect a very gradual change in a stimulus (Neuhoff, Wayand, Ndiaye, Berkow, Bertacchi, & Benton, 2015).

Unfortunately, there appears to be several potential issues that complicate the demonstration of change deafness within these paradigms. Reliance on these methods raises the possibility that at least some detection errors could be attributable not to change deafness, but rather to informational masking effects resulting from target and distractor uncertainty (Dickerson & Gaston, 2014). For example, the use of arrays containing a large number of events

increases uncertainty beyond levels that are typical of change deafness demonstrations.

Consistent with this possibility, McAnally et al. (2010) reviewed participants' event encoding on both detected and non-detected change trials, finding that changes were only detected when events were encoded well. Contrasting findings also have been reported. For example, Gregg and Samuel (2008) measured change detection and event encoding [using an approach similar to how Mitroff, Simons and Levin (2004) evaluated encoding errors relative to change blindness] and found that participants often failed to detect changes even when events appeared to be encoded well. It is noteworthy, however, that both sets of findings required the evaluation of encoding in a task that was separate from the one used to evaluate change deafness; thus, the two tasks might reflect different task demands on the listener that further complicates the interpretation of error rates.

An additional concern is that studies of change deafness using a one-shot paradigm or a single-trial change task frequently instruct a participant to selectively attend to one event while a change is made to an unattended event. The misdirection of selective attention more accurately represents a related phenomenon termed 'inattentional deafness' rather than change deafness (Peck, Hall, Gaston and Dickerson, 2017). This is a distinction first mentioned for visual attention as 'change blindness' versus 'inattentional blindness'. In contrast to change blindness, inattentional blindness occurs when an observer fails to detect a change in a visual stimulus because attention has been diverted as a result of an experimenter's instructions (Rensink, 2009). Similarly, inattentional deafness demonstrations include instructions for an observer to selectively attend to one, specific stimulus, thereby diverting attention away from another, changing stimulus. While change deafness and inattentional deafness are certainly related concepts, they are not identical processes and should not be used interchangeably.

Change deafness has alternatively been explored using methods that are more akin to those that have been used to study change blindness, including a flicker paradigm and a continuous method. In a flicker paradigm, an auditory stimulus alternates (i.e., flickers) between a standard and a variant version of itself, while in a continuous method an auditory stimulus will gradually change (Peck et al., 2017). In both cases a participant identifies when they perceive the changing element in the array. Unlike the one-shot paradigm, both flicker and continuous methods allow for sufficient exposure to stimuli to ensure that participants properly encode array events. Peck et al. (2017) used both flicker and continuous methods to assess whether failure to detect shifts in auditory location is indicative of a change deafness mechanism that operates analogously to that involved in change blindness. The same four events were presented throughout their experiment in an aim to maximize a participant's ability to fully encode each array, thus greatly reducing error rates. Error rates were minimal under flicker conditions, whereas continuous conditions produced elevated error rates reflective of change deafness. This suggests that the sudden and rapid changes present in a flicker paradigm make shifts in auditory location more distinct, and thus, more easily detected.

A fundamental issue that remained to be addressed was why change deafness occurs, or more specifically, what aspects of stimuli or processing are responsible for it. There had been no established explanation as to what effectively gives rise to change deafness. For instance, Gregg and Snyder (2012) raise a fundamental question concerning why listeners would miss changes even when neurophysiological data report brain activity in the area representing an implicit change detection mechanism. Such findings support the fact that these auditory changes are above threshold. As a result, listeners should be able to perceive them. Other researchers have questioned how the type of stimuli, their relationship to one another, or the manner in which they

are presented to an observer may prevent changes from reaching conscious awareness. For example, Dickerson and Gaston (2014) propose that the magnitude of errors is likely related to the extent to which there is stimulus ambiguity, high information load, and misdirected allocation of a participant's attention.

Among potentially relevant stimulus variables, similarity of events could easily be argued to be the most likely to influence change deafness. The more dissimilar a stimulus is from other events in an array, the more noticeable it should be to a listener. Some suggestion for this argument comes from studies of change blindness. For example, when various aspects of an image are manipulated, participants detect changes of objects more accurately than surface color or shadow changes, presumably because participants perceive an object as more significant than other features of an image; furthermore, change detection performance can be predicted by the perceived significance of image regions involved in the change (Wright, 2005). Dickerson and Gaston (2014) also have suggested that the similarity of auditory stimuli should correlate to patterns of errors observed during change detection procedures. Additionally, it has been argued that participants perceive changes most accurately when the target is distinct from the background at both semantic and perceptual levels (Gregg & Samuel, 2008, 2009).

While it appears that similarity should predict the occurrence of change deafness, this possibility has not been directly tested. Addressing this issue constitutes a first step toward understanding what is responsible for people missing important information that is well above threshold. The present investigation therefore used a variant of the continuous-change approach (see Peck et al., 2017) to evaluate how the similarity of stimuli influences auditory change detection. Event similarity was manipulated by adjusting timbre, the perceived quality that is used to identify the sound source. Participants were instructed to detect a change (e.g., with

respect to location in perceived space) in one target event that had either a shared or dissimilar timbre relative to distractor events. It was hypothesized that listeners would be faster and more accurate at detecting changes when the target event was perceptually dissimilar to distractors.

Method

Participants

Participants included 27 James Madison University students from the Department of Psychology's participant pool who participated in partial fulfillment of course requirements. Participants had self-reported normal hearing, and participant age ranged from 18 to 23 years ($M = 19.83$, $SD = 1.59$), therefore minimizing problems due to presbycusis (high-frequency hearing loss associated with age).

Participants completed a brief survey of musical history that was recently developed in our laboratory, the Musical Training and Experience (MUTE) survey (Hall, Daly, Gaston, & Dickerson, 2017). Items on this survey include questions regarding experience with musical instruments/voice, music lessons, music history courses, music ensembles, and musical video games (see Appendix). This survey was included to gain a sense of the range of musical abilities within the sample, which could be critical to general levels of performance in the task.

Completed responses from the survey indicate the average duration of time spent playing an instrument (including voice) was 6.31 years ($SD = 4.96$), the average duration of receiving private music lessons was 2.77 years ($SD = 3.88$), and the average duration of experience as a member in a musical ensemble was 5.08 years ($SD = 5.01$). Data from the survey also could ultimately be used to evaluate whether some participants may have performed better at the task due to familiarity with particular musical instrument sounds.

For data to be analyzed, it had to first meet an a priori performance criterion. This criterion was 40 percent correct responses in the condition hypothesized to be the easiest for participants to correctly answer, where the target's timbre was dissimilar to both distractor events. This criterion was selected to ensure that performance in what was expected to be the simplest condition was at least above chance levels (33 percent correct) so that we could be sure that listeners were making an effort to appropriately complete their task (see *Procedure* below). However, a lax criterion was selected because we also expected high error rates, which potentially could indicate the frequent occurrence of change deafness. Despite this relatively lax criterion, 14 of the 27 participants did not meet or exceed this requirement. As a result, reported analyses were restricted to data from the remaining 13 participants.

Stimuli

Stimuli included arrays composed of a combination of three sustained, synthesized vowel tones. Each tone had an inharmonic pitch relationship to each other to avoid perceptual fusion of simultaneous components and to minimize error in perceived tone location (see Roberts & Bregman, 1991; Bonnard, Dauman, Semal, & Demany, 2016). Tones varied with respect to timbre. There were two vowel timbres. The vowel /a/ and /i/ were used due to their sharp contrast with respect to spectral envelope shape (Klatt, 1980). Tones were synthesized for three chroma: A_2 ($F_0 = 110$ Hz), $D^{\#}_3$ ($F_0 = 155.56$ Hz), and B_3 ($F_0 = 246.94$ Hz). Tones were derived from natural productions of /a/ and /i/ by a male speaker of American English. Amplitudes for each of the first 50 harmonics were measured at the midpoint of the vowel. Those values were then submitted to a *MaxforLive* device of the laboratory's creation. This device resynthesizes up to 50 harmonics, with the specified amplitudes, and additionally, interpolates between frequency values to generate amplitude values at frequencies other than those that were present in the

original sample. All individual tones were matched for average root mean squared (RMS) amplitude. Tones were digitized with a minimum sampling rate of 44.1 kHz (16 bit-depth resolution). The three events were time-stretched or looped around the middle segment of the tone (i.e., post-attack and pre-release) to be equal in duration (8 s). All events reflected 10 ms linear ramps in amplitude at both tone onset and offset.

Virtual starting positions for the tones were assigned using a VST plug-in, *Panorama 5* (WaveArts, Inc., 2012), within a digital audio workstation program, Ableton's *Live Suite* (v. 9.7). Each event had a unique virtual starting position with a 40-degree difference between adjacent tones (-40°, 0°, +40°) on the azimuth, which was distributed across the level of a participant's ear. The *Panorama 5* plug-in assigned a constant virtual distance of 20 feet.

The target event, which was defined as the event that changed location, moved continuously and oscillated at a naturally occurring rate of 0.33 Hz. In each array, the sole target event moved 60° across the azimuth (i.e., -40° to +20°, 0° to +60°, 0° to -60°, or +40° to -20°). Henceforth, the following abbreviated labels, which focus on starting positions for target events, will be used to refer to each movement pattern: -40° represents movement from the left to the right; -0° represents movement from center to the left, +0° represents movement from center to the right; and +40° represents movement from the right to the left. Two tones within any array shared a vowel timbre, and the third tone had a different timbre. Across arrays, the target event was equally likely to share a similar or dissimilar timbre with one of the other array events.

All possible combinations of tone events were represented over 192 randomized arrays. The peak amplitude for all individual arrays did not exceed 80 dB[A]. Participants listened to stimuli over Sennheiser HD 25-SP II Headphones in a sound-attenuated chamber.

Procedure

After completing the Musical Training and Experience (MUTE) survey, participants began the experiment. Stimulus presentation, timing, and collection of participant responses were computer-controlled through Empirisoft's *DirectRT* version 2016 (Jarvis, 2016a). Prior to the experimental task, participants were familiarized with both vowels at each pitch, each tone's potential starting position across the azimuth, and the various movements of the tones. Each example during this task was accompanied by text describing the specific stimulus being presented. First, in a centered location, each timbre was presented at each pitch in non-random, cycled order (i.e., low /a/, middle /a/, high /a/; low /i/, middle /i/, high /i/). Accompanying text read either "This is a low pitch", "This is a middle pitch", or "This is a high pitch", respectfully. Second, one timbre at one specified pitch (e.g., middle /a/) was presented at each starting location in a cycle from left to right on the azimuth (-40° , 0° , $+40^\circ$). Third, both vowels at one pitch were played at two starting locations with movement (e.g., middle /a/ beginning at -40° , middle /a/ beginning at $+40^\circ$, middle /i/ beginning at $+40^\circ$, middle /i/ beginning at -40°). For the first two familiarization procedures, the entire cycle of presented stimuli was repeated three times (the third only once), and adjacent stimuli were separated by a 1,000 *ms* inter-stimulus interval (ISI). Participants were instructed to listen for the critical difference(s) between stimuli in each familiarization procedure, and no responses were made/collected at this time.

Before beginning the experimental trials, participants were informed that their task was to select the event, defined by pitch (low, middle, or high), that has changed locations (i.e., the target event) as quickly and accurately as possible. Each trial consisted of a randomly selected array. Participants indicated their responses by pressing a corresponding button on a high-speed button-box, *DirectIN* (Jarvis, 2016b), that allows millisecond timing accuracy. Buttons were

labeled as “L”, “M”, and “H” to represent the three possible pitches (i.e., low pitch, middle pitch, high pitch).

The task consisted of a single block of 192 trials in which each array was presented once. The task was self-paced, but completed in approximately 60 minutes.

Results

The probability of a correct response was determined for each participant for every possible combination of timbre (/a/ and /i/), pitch (low, middle, high), intended pattern of target movement (-40°, -0°, +0°, +40°), and similarity (similar and dissimilar). The resulting values were submitted to corresponding 2x3x4x2 repeated measures ANOVA. Post hoc pairwise comparisons of means were accomplished using a Bonferroni correction. Assumptions of sphericity were not violated.

A complete listing of mean probabilities of a correct response, along with corresponding standard errors of the mean, for each stimulus condition/combination of levels across variables, is provided in Table 1. Likewise, a complete listing of F-ratios, p-values, and effect sizes for each combination of variables from the ANOVA is provided in Table 2. However, since only a few major effects were observed, included figures within the text are limited to cases where statistically significant differences were obtained from the data.

Figure 1 displays mean probabilities of a correct response and corresponding standard errors as a function of similarity. As can be seen in the figure, there was a tendency for people to be more accurate when the target did not share a timbre with the other two distractors (i.e., in the dissimilar condition). This tendency was confirmed by a main effect of similarity, the major variable of interest, $F(1, 12) = 19.06, p < 0.001, \text{partial } \eta^2 = 0.614$.

Figure 2 instead displays mean probabilities of a correct response and corresponding standard errors as a function of location. The pattern of average data within the figure reflects a tendency for people to be more accurate when the starting locations for the target event were at -40° or $+40^\circ$ (i.e., tones with a starting location that should have been perceived as either farthest to the left or to the right of the listener). This was confirmed by a main effect of the intended pattern of target movement, $F(3, 36) = 4.811, p = 0.006$, partial $\eta^2 = 0.286$. Subsequent pairwise comparisons of means further revealed a marginal tendency toward greater accuracy when the target began on the far left (i.e., the $+40^\circ$ condition) relative to when it began in the center and moved to the left (-0°). No other significant effects were obtained.

Discussion

In the present experiment, the primary hypothesis anticipated a lower mean percent correct identification of target events that shared timbre with a distractor. This pattern was supported (see Figure 1). This finding is consistent with change deafness, suggesting that the occurrence of this phenomenon depends upon the degree of event similarity. It is noteworthy that this support for similarity's influence on change deafness was obtained despite the fact that the manipulation of similarity in the current investigation was restricted to one acoustic property within a single array event.

It could be argued that this interpretation already was anticipated by earlier auditory research. For example, Gregg and Samuel (2008) found that change detection performance in a one-shot paradigm increased when the changing event was more acoustically distinct from the sound it replaced. However, the major findings from the present study represent a novel contribution on several grounds. For instance, perceived similarity played a role in the obtained error rates was provided by the fact that efforts were taken to minimize possible encoding issues.

Alternative methods that have been used to study change deafness, including the one-shot method, raise concerns regarding the true source of error rates due to the high number of events on each trial in addition to inadequate time with arrays to properly encode or make an accurate decision. Although previously used methods likely also produced many instances of true change deafness errors, these cannot be viewed in isolation from possible encoding errors.

It is unlikely that many errors during our study reflected difficulty encoding the stimuli. There were only three co-occurring tones per trial, and the same tone stimuli were used throughout the experiment. Additionally, the familiarization task introduced each tone in conjunction with its corresponding text description before any responses were collected. Also, each pitch was carefully selected to form an inharmonic relationship with other pitches in a given array, with each differing by more than a third of an octave. This decision was based on previous investigation for the perceptual segregation of simultaneous auditory sounds, finding that components of a harmonic series tend to fuse together due to their association with a particular fundamental frequency (Chalikia & Bregman, 1993). Creating an inharmonic relationship acts against the chance of perceptually fusing all tones into one massive event, which would otherwise be a concern for accurate encoding.

Additionally, regardless of encoding issues, studies involving the one-shot paradigm rely on a considerably different construct to account for similarity (see Mitroff, Simmons & Levin, 2004; Gregg & Samuel, 2008; Snyder & Gregg, 2011). For example, Gregg and Samuel (2008) varied the amount of similarity between the target and the event the target replaced. In contrast, our approach was novel in that it compared a target event to other events in the array. Dickerson and Gaston (2014) had suggested that the latter distinction relates directly to performance. However, this idea had not actually been evaluated until now.

Ruling out the possibility of encoding errors, one might still argue that the major findings concerning similarity were due to differences in task difficulty rather than change deafness. Indeed, this task proved to be very difficult, as indicated by the low overall performance on our experimental procedure and the need to exclude data from a majority of our participants for failing to meet the a priori performance criterion. Data from 14 participants were not analyzed because their performance fell below 40 percent correct responses in the condition reflecting dissimilarity between the target and distractor timbres. An argument thus could be made that our findings only apply to individual's with inherently better perceptual abilities. For example, it is possible that the majority of participants may have had greater difficulty performing the task accurately as a result of their relatively minimal personal inexperience with judging perceived musical properties within an ensemble. This concern could potentially be reduced in future studies by collecting data during familiarization in order to ensure full participant understanding before beginning the experimental task.

Task difficulty still does not explain the difference between performance in the similar and dissimilar conditions. While it is true that performance for both conditions was generally poor, it was worse when the target and a distractor shared timbre. Both conditions shared all parameters except for one; the similarity of timbre. Therefore, similarity remains the only reasonable explanation as to why a difference in error rate across conditions was observed.

This support for similarity impacting change deafness has important implications for previous research on change deafness and auditory change detection. The possibility of perceived similarity of array events influencing error rates may be present in previous experiments. For example, Eramudugolla, Irvine, McAnally, Martin, and Mattingley (2005) measured error rates reflective of change deafness as a function of attention to complex scenes.

Participants were instructed to identify the changing event in an array of four to eight simultaneously co-occurring events. The pattern of results revealed a decrease in accurate change detection as the number of events in a trial increased. As the number of array events increases, there is a greater likelihood that events will overlap in similarity, both in acoustic properties (e.g., spectral envelope shape) and spatial location. As a result, it is possible that increased error rates reflective of change deafness in Eramudugolla, et al. (2005) and related studies that relied upon the one-shot paradigm were due, at least in part, to increasing similarity, but this possibility has not been directly investigated.

In contrast to the one-shot paradigm, our study reflected a continuous-change method, such as the one used in a study by Peck et al. (2017). Nevertheless, despite the fact that both studies involved identifying the sole moving target within an array of repeatedly presented events, results from the two studies reflect drastically different error rates. The difference in obtained error rates between these two studies is likely due to remaining differences in methodology. Only the current investigation directly manipulated similarity between array events, relied upon tone events that consisted of static spectral envelope shapes, and required pitch judgements. Furthermore, in recognition that these decisions likely increased task difficulty, we limited the number of array events to only three tones. Despite these efforts, this task clearly remained difficult for listeners.

This does not mean, however, that perceived similarity did not play a role in the change deafness that Peck et al. (2017) observed. They argued that change deafness occurred in their study when changes in the target's spatial location from one sampling of time to the next were too small to be perceived as a change. Taken together with the major findings from the current investigation, this suggests that change deafness could be based upon several forms of perceived

similarity. While Peck et al. (2017) considers the perceived similarity of event locations, the present study additionally indicates change deafness derived from the perceived similarity between the array events themselves.

The major findings from the current investigation also are congruent with findings regarding similarity's influence on change blindness. After all, such studies in change blindness form the basis for our initial hypothesis. Early investigations by Rensink, O'Regan, and Clark (1997) explained that the occurrence of change blindness depends upon the perceived significance of a changing aspect of a scene. While perception of significance may subjectively vary across individuals, it is likely contingent upon the stimuli that appear most noticeable to an observer. Our construct of similarity in the present study can be interpreted in a corresponding manner. Specifically, the timbre of an event was manipulated for all tones in an array, allowing for two conditions in which the target event did, or did not, share the same timbre as a distractor. When the target event was dissimilar from the other two array events, the contrasting timbre likely emerged as significant to a listener, and therefore, was more easily identifiable. It remains for future research to determine if this finding extends to further auditory (and visual) stimulus manipulation.

Data from the current investigation also revealed a statistically significant difference in mean percent correct identification of change as a function of the target event's starting location. Specifically, listeners were better at identifying the pitch of the target tone when that tone was first presented to their immediate left (-40° on the azimuth) or their immediate right ($+40^\circ$ on the azimuth) rather than in the center (0° on the azimuth). Following the experimental task, participants shared with the researcher the type of strategies that they used to complete the task. A commonly reported strategy was to isolate the tones by location (e.g., first listening to the left,

the center, or the right of the azimuth), and five participants further specified that they began by listening to one ear at a time (e.g., the left or the right). Following this strategy, more focus and attention was placed on the left or right location (then switching to the other ear) and therefore, less time was allocated to the center location. Because the center location was equally close in spatial position to the left and right event locations, it may have been more difficult to isolate from simultaneous events. Furthermore, a target event that started at the left or the right location would never cross paths with the tone at the opposite end of the azimuth, whereas a tone starting at the center location had two possible target movement patterns, both of which moved further into the periphery than one of the distractors. As a result, targets beginning in the center location were most likely to be mistaken with either the tone to left or right, leading to poorer performance.

The effect of location on error rates, along with the generally poor levels of overall performance, is consistent with evidence from related tasks. For example, Shinn-Cunningham and Ihlefeld (2004) demonstrated that listeners were significantly worse at accurately identifying a component of the target event when the location changed from trial to trial, relative to when the target event had a fixed location across trials. Furthermore, previous research has demonstrated that localization performance significantly declines when two distractors are included (Langendijk, Kistler, & Wightman, 2001). If an alternative manipulation for similarity was generated that avoided the use of location within the critical aspects of the task (e.g., by modulating the amplitude of target events), then it is likely that more optimal levels of performance could be obtained in instances where change deafness does not occur. This would greatly simplify assessment of the incidence of change deafness so that an effective

determination could be made regarding how often change deafness occurs across various environmental conditions. Our research laboratory is currently exploring this possibility.

References

- Bonnard, D., Dauman, R., Semal, C., & Demany, L. (2016). Harmonic fusion and pitch affinity: Is there a direct link?. *Hearing research, 333*, 247-254.
- Chalikia, M. H., & Bregman, A. S. (1993). The perceptual segregation of simultaneous vowels with harmonic, shifted, or random components. *Perception & psychophysics, 53*(2), 125-133.
- Dickerson, K., & Gaston, J. R. (2014). Did you hear that? The role of stimulus similarity and uncertainty in auditory change deafness. *Frontiers in psychology, 5*.
- Eramudugolla, R., Irvine, D. R., McAnally, K. I., Martin, R. L., & Mattingley, J. B. (2005). Directed attention eliminates 'change deafness' in complex auditory scenes. *Current Biology, 15*(12), 1108-1113.
- Gregg, M. K., & Samuel, A. G. (2008). Change deafness and the organizational properties of sounds. *Journal of Experimental Psychology: Human Perception and Performance, 34*(4), 974.
- Gregg, M. K., & Samuel, A. G. (2009). The importance of semantics in auditory representations. *Attention, Perception, & Psychophysics, 71*(3), 607-619.
- Gregg, M. K., & Snyder, J. S. (2012). Enhanced sensory processing accompanies successful detection of change for real-world sounds. *Neuroimage, 62*(1), 113-119.
- Hall, M. D., Daly, H., Gaston, J. & Dickerson, K. (2016, November). The differential impacts of task demands on change deafness and inattentional deafness. Poster presented at the 57th Annual Meeting of the Psychonomic Society, Boston, Massachusetts.
- Jarvis, B. G. (2016b). DirectIN (Version 2016) [Computer Hardware]. New York, NY: Empirisoft Corporation.

- Jarvis, B. G. (2016a). DirectRT (Version 2016) [Computer Software]. New York, NY: Empirisoft Corporation.
- Klatt, D. H. (1980). Speech perception: A model of acoustic-phonetic analysis and lexical access. *Perception and production of fluent speech*, 243-288.
- Langendijk, E. H., Kistler, D. J., & Wightman, F. L. (2001). Sound localization in the presence of one or two distracters. *The Journal of the Acoustical Society of America*, 109(5), 2123-2134.
- Levin, D. T., & Simons, D. J. (1997). Failure to detect changes to attended objects in motion pictures. *Psychonomic Bulletin & Review*, 4(4), 501-506.
- McAdams, S., Winsberg, S., Donnadieu, S., De Soete, G., & Krimphoff, J. (1995). Perceptual scaling of synthesized musical timbres: Common dimensions, specificities, and latent subject classes. *Psychological research*, 58(3), 177-192.
- McAnally, K. I., Martin, R. L., Eramudugolla, R., Stuart, G. W., Irvine, D. R., & Mattingley, J.B. (2010). A dual-process account of auditory change detection. *Journal of Experimental Psychology: Human Perception and Performance*, 36(4), 994.
- Mitroff, S.R., Simons, D.J., & Levin, D.T. (2004). Nothing compares 2 views: Change blindness can occur despite preserved access to the changed information. *Attention, Perception, & Psychophysics*, 66(8), 1268-1281.
- Neuhoff, J. G., & Bochtler, K. S. (2017). Change deafness, dual task performance, and domain-specific expertise. *The Quarterly Journal of Experimental Psychology*, (just-accepted), 1-42.

- Neuhoff, J. G., Wayand, J., Ndiaye, M. C., Berkow, A. B., Bertacchi, B. R., & Benton, C. A. (2015). Slow change deafness. *Attention, Perception, & Psychophysics*, 77(4), 1189-1199.
- Opolko, F. J., Wapnick, J., & McGill University. (2006). *MUMS: McGill University master samples*. Montreal, Quebec, Canada: Faculty of Music, McGill University. [Sound recording]
- Pashler, H. (1988). Familiarity and visual change detection. *Perception & Psychophysics*, 44(4), 369-378.
- Peck, R. B., Hall, M. D., Gaston, J. R., & Dickerson, K. (2017). Evidence of change deafness with continuously moving targets. Department of Psychology, James Madison University, Harrisonburg, Virginia.
- Rensink, R.A. (2009). "Attention: Change blindness and inattention blindness." In W. Banks (Ed.), *Encyclopedia of Consciousness*, Vol 1 (pp. 47-59). New York: Elsevier.
- Rensink, R. A. (2002). Change detection. *Annual review of psychology*, 53(1), 245-277.
- Rensink, R. A., O'Regan, J. K., & Clark, J. J. (1997). To see or not to see: The need for attention to perceive changes in scenes. *Psychological science*, 8(5), 368-373.
- Roberts, B., & Bregman, A. S. (1991). Effects of the pattern of spectral spacing on the perceptual fusion of harmonics. *The Journal of the Acoustical Society of America*, 90(6), 3050-3060.
- Shinn-Cunningham, B. G., & Ihlefeld, A. (2004). Selective and Divided Attention: Extracting Information from Simultaneous Sound Sources. In *ICAD*.
- Simons, D. J. (1996). In sight, out of mind: When object representations fail. *Psychological Science*, 7(5), 301-305.

Snyder, J. S., & Gregg, M. K. (2011). Memory for sound, with an ear toward hearing in complex auditory scenes. *Attention, Perception, & Psychophysics*, *73*(7), 1993.

Wave Arts, Inc. (2012) Panorama 5 [Computer software]

Wright, M. J. (2005). Saliency predicts change detection in pictures of natural scenes. *Spatial vision*, *18*(4), 413-430.

Appendix

Musical Training and Experience (MUTE) survey

Musical Training Survey

Participant #: _____

1. What is your birthdate? ____/____/____ (MM/DD/YYYY)

2. Have you ever taken a formal music class? (include elementary/grade school music classes, theory, choir, band, etc).

 yes noIf answering *yes*, please select the types of classes that best match your experience (check all that apply):

elementary class music appreciation music theory ear training band/choir
 music history music composition conducting piano
 other (please describe) _____

3. How many college-level music courses have you completed? _____ courses

Please list all courses and indicate if you are currently enrolled in any of them:

4. Have you ever played a musical instrument or studied singing? (if no, please skip to question #16)

 yes no5. What style of music do you play most often (select *one*):

Classical Pop Jazz Folk Rock Country
 Other _____

6. What instrument(s) have you played (including voice)?

How many months/years have you studied/played each instrument (or voice)? Please indicate both duration and the corresponding instrument:

7. At what age did you begin playing/studying music? _____ years old

8. Approximately how many hours per week did you spend practicing music during your first year of study? _____ hours/week

9. Are you currently involved in any musical activities? If not, at what age did you stop playing music?

yes (currently involved) no (not involved) ____ age that you stopped, if applicable

10. If you are currently involved in musical activities, about how many hours do you spend playing music per week, including rehearsal and individual practice? (if not currently practicing, skip to next question) ____ hours/week

11. Are you currently or have you ever received private music lessons?

yes (currently receiving) yes (received in the past) no (no history of private lessons)

12. How many years/months of experience do you have taking private music lessons?

____years/____months

13. Are you currently or have you ever participated in a musical ensemble? (e.g. band/choir class, honor bands/choirs, informal musical ensembles, church music group, community ensembles, any situation in which you create music with others):

yes (currently participating) yes (participated in the past) no (no history of participation)

14. How many years/months of experience do you have participating in a musical ensemble?

____years/____months

Please describe all ensembles and how many years you participated in each:

15. How many years/months of improvisation experience do you have? (playing music spontaneously, not following written musical notation)

____years/____months

16. How many years/months of experience do you have composing/writing music?

____years/____months

17. How many years/months of experience do you have creating or manipulating music using a computer? (DJ, electronic music, etc.):

____years/____months

18. How many year/months of experience do you have participating in musical theatre? How many musicals have you participated in?

____years/____months _____ musicals

Please describe your role in these musical theatre productions (performer, stage crew, orchestra):

19. How many years/months of dance experience do you have? (ballet, jazz, tap, color guard, etc.)

____years/____months

Please describe all dance styles and how many years you participated in each:

20. How many years/months of experience do you have playing musical video games? (Guitar Hero, Rock Band, etc.)

____years/____months

Table 1.

Means and Standard Errors for All Combinations of Timbre (/a/, /i/), Pitch (L, M, H), Pattern of Target Movement (-40°, -0°, +0°, +40°), and Similarity (Similar, Dissimilar)

<i>Timbre</i>	<i>Pitch</i>	<i>Movement</i>	<i>Similarity</i>	<i>M</i>	<i>SE</i>
/a/	L	-40°	S	0.500	0.098
/a/	L	-40°	D	0.654	0.096
/a/	L	-0°	S	0.423	0.087
/a/	L	-0°	D	0.615	0.073
/a/	L	+0°	S	0.519	0.072
/a/	L	+0°	D	0.635	0.088
/a/	L	+40°	S	0.538	0.089
/a/	L	+40°	D	0.654	0.083
/a/	M	-40°	S	0.442	0.081
/a/	M	-40°	D	0.712	0.079
/a/	M	-0°	S	0.462	0.084
/a/	M	-0°	D	0.731	0.100
/a/	M	+0°	S	0.519	0.096
/a/	M	+0°	D	0.750	0.057
/a/	M	+40°	S	0.558	0.086
/a/	M	+40°	D	0.731	0.077
/a/	H	-40°	S	0.519	0.100
/a/	H	-40°	D	0.750	0.069
/a/	H	-0°	S	0.385	0.083
/a/	H	-0°	D	0.615	0.088
/a/	H	+0°	S	0.404	0.096
/a/	H	+0°	D	0.615	0.104
/a/	H	+40°	S	0.692	0.090
/a/	H	+40°	D	0.750	0.080
/i/	L	-40°	S	0.692	0.095
/i/	L	-40°	D	0.635	0.101
/i/	L	-0°	S	0.538	0.097
/i/	L	-0°	D	0.596	0.096
/i/	L	+0°	S	0.462	0.084
/i/	L	+0°	D	0.481	0.104
/i/	L	+40°	S	0.500	0.094
/i/	L	+40°	D	0.654	0.092
/i/	M	-40°	S	0.404	0.072
/i/	M	-40°	D	0.519	0.082
/i/	M	-0°	S	0.442	0.106
/i/	M	-0°	D	0.481	0.082
/i/	M	+0°	S	0.462	0.101
/i/	M	+0°	D	0.385	0.092

Table 1 Continued.

<i>Timbre</i>	<i>Pitch</i>	<i>Starting Location</i>	<i>Similarity</i>	<i>M</i>	<i>SE</i>
/i/	M	+40°	S	0.500	0.094
/i/	M	+40°	D	0.500	0.094
/i/	H	-40°	S	0.327	0.115
/i/	H	-40°	D	0.538	0.120
/i/	H	-0°	S	0.250	0.075
/i/	H	-0°	D	0.404	0.104
/i/	H	+0°	S	0.327	0.091
/i/	H	+0°	D	0.462	0.105
/i/	H	+40°	S	0.404	0.087
/i/	H	+40°	D	0.635	0.092

Table 2.

Inferential Statistics of Within-Subject Effects

Variable(s)	<i>F</i>	<i>df</i>	<i>p</i>	partial η^2
Timbre	3.239	1, 12	0.097	0.213
Pitch	2.720	2, 24	0.086	0.185
Location	4.811	3, 36	0.006	0.286
Similarity	19.06	1, 12	0.001	0.614
Timbre*Pitch	2.990	2, 24	0.069	0.199
Timbre*Location	0.855	3, 36	0.473	0.067
Timbre*Similarity	3.332	1, 12	0.093	0.217
Pitch*Location	1.570	6, 72	0.168	0.116
Pitch*Similarity	1.271	2, 24	0.299	0.096
Location*Similarity	0.532	3, 36	0.663	0.042
Timbre*Pitch*Location	0.972	6, 72	0.451	0.075
Timbre*Pitch*Similarity	2.786	2, 24	0.082	0.188
Timbre*Location*Similarity	1.060	3, 36	0.378	0.081
Pitch*Location*Similarity	0.439	6, 72	0.850	0.035
Timbre*Pitch*Location*Similarity	0.299	6, 72	0.936	0.024

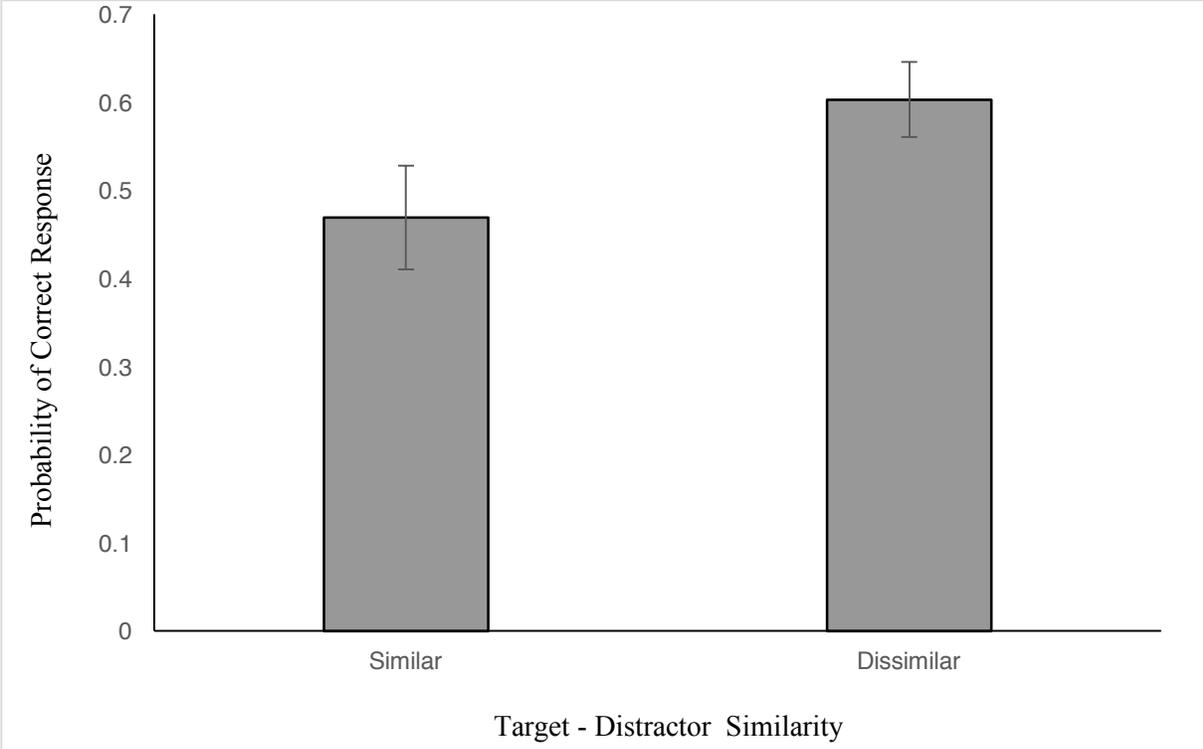


Figure 1. Mean probability of a correct response and corresponding standard errors as a function of similarity between the moving target and one distractor.

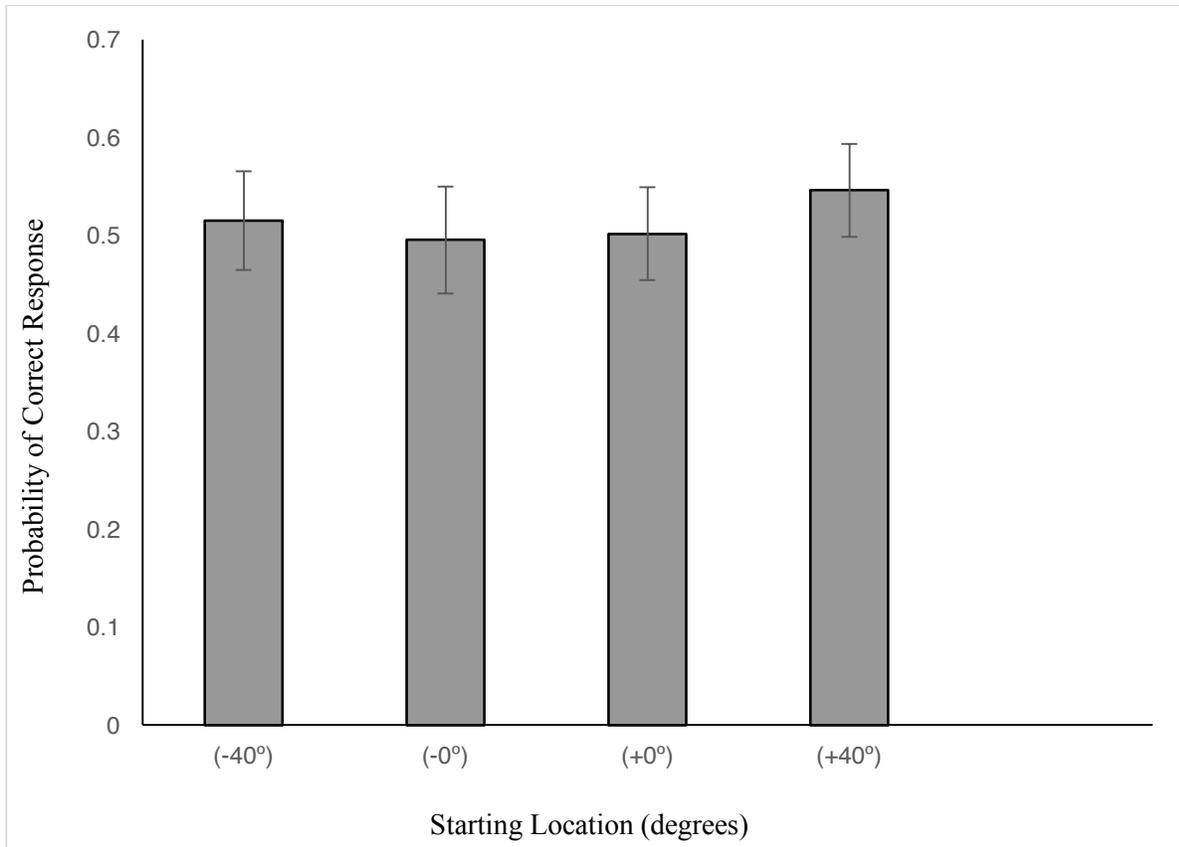


Figure 2. Mean probability of a correct response and corresponding standard errors as a function of the target's starting location [far left (-40°); center moving left (-0°); center moving right (+0°); far right (+40°)].