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Change deafness, dual-task performance, and domain-specific expertise

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Abstract

In a change deafness manipulation using radio broadcasts of sporting events, we show that change deafness to a switch in talker increases when listeners are asked to monitor both lexical and indexical information for change. We held semantic content constant and demonstrated a change deafness rate of 85% when participants listened to the home team broadcast of a hockey game that switched midway to the away team broadcast with a different announcer. In Study 2, participants were asked to monitor either the indexical characteristics (*listen for a change in announcer*) or both the indexical and semantic components (*listen for a change in announcer or a goal scored*). Monitoring both components led to significantly greater change deafness even though both groups were alerted to the possibility of a change in announcer. In Study 3, we changed both the indexical and the semantic components when the broadcast switched from a hockey game to a basketball game. We found a negative correlation between sports expertise and change deafness. The results are discussed in terms of the nature of perceptual representation and the influence of expertise and evolution on attention allocation.

Keywords

Change deafness; expertise; auditory attention; perceptual representation; evolution; sports

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Our access to the external world is limited in bandwidth and hierarchically constrained to the features of the environment that are most critical. Although subjectively it may seem as though we perceive all of the stimuli with which we are presented, a large body of research now shows that this simply is not true. Change blindness studies show that objects or people in full view can be replaced with markedly different objects or people, and the change often goes unnoticed (for reviews, see Boloix, 2007; Cohen, Dennett, & Kanwisher, 2016; Jensen, Yao, Street, & Simons, 2011; Simons & Chabris, 1999; Simons & Rensink, 2005; Tomonaga & Imura, 2015). Inattentional blindness studies demonstrate that under high attentional load, an object as eye-catching as a gorilla can enter the center of a visual scene, but still go unnoticed by the observer (Simons & Chabris, 1999).

In the auditory domain, analogous change deafness phenomena have been identified. A voice in a conversation can be replaced with markedly different one and go unnoticed (Fenn et al., 2011). Inattentional deafness studies have similarly shown that if auditory attentional load is high, conspicuous intervening sounds often go unnoticed (Dalton & Fraenkel, 2012). Although the specific mechanisms underlying these phenomena are still a topic of some debate, a clear conclusion that can be drawn is that our perception of the environment is not veridical (Hoffman, Singh, & Prakash, 2015).

Perhaps we should not be surprised at failures to detect changes that occur in an experimental setting that would almost never occur in a natural environment. Failing to notice changes in stimuli that rarely change could free cognitive resources for attention to other more critical stimuli that do change. Thus, rather than being considered "perceptual error," it could be that failure to detect change and other perceptual distortions of the environment are sometimes advantageous. Examples of beneficial perceptual errors include perceiving threatening objects as closer and as moving faster than non-threatening objects (Brendel, Hecht, DeLucia, & Gamer, 2014; Neuhoff, 2001, 2016; Vagnoni, Lourenco, & Longo, 2012, 2015; Witt & Sugovic, 2013) and overestimating height above the ground based on the

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consequences of falling (Stefanucci, Gagnon, Tompkins, & Bullock, 2012). Although they are technically perceptual errors (false positives), these errors have a small cost compared to making analogous false-negative errors (Haselton et al., 2009). Thus, although there is obviously considerable overlap between the two, perceptual representations can sometimes be biased toward "utility" rather than toward "accuracy" (Neuhoff, 2016).

Change deafness

In the auditory realm, two different methodologies have typically been used to examine change deafness. The first method presents listeners with a single sound source (e.g., a voice) and changes the identity of the source midway through the auditory presentation. At the end of the presentation, listeners are asked a series of increasingly specific questions to determine if they detected the change. For example, in one of the first change deafness studies, Vitevitch (2003) had participants shadow lists of words that they heard over headphones. Midway through the list, the voice reading the word list was switched to that of another talker. Across several experiments, at least 40% of the participants failed to detect the change, and the likelihood of detection was related to word processing time. Those who allocated more attention to shadowing the words were less likely to detect the change in talker. Other studies have used a similar methodology in the context of a phone conversation (Fenn et al., 2011), in listening to a familiar or unfamiliar language (Neuhoff, Schott, Kropf, & Neuhoff, 2014), or in detecting a gradual change in a talker over time (Neuhoff et al., 2015).

The second method used to examine change deafness has been to present a single change to a complex auditory scene. Listeners hear a clip of an acoustic scene composed of multiple simultaneously sounding objects followed by a very brief pause (either a burst of noise or silence). The array is then presented once again with either one of the sounding objects missing or an additional object present. The listener's task is to determine if the two presentations were the same or different. This method has been used to examine change deafness of human voices (Kawashima, 2015), natural sounds (Asutay & Vastfjall, 2014; Gregg & Snyder, 2012; Pavani & Turatto, 2008), musical sounds (Schnuerch, Kreitz, Heil, & Lange, 2014), artificial sounds produced in the laboratory (Constantino, Pinggera, Paranamana, Kashino, & Chait, 2012; Demany, Trost, Serman, & Semal, 2008; Puschmann et al., 2013; Sohoglu & Chait, 2016), and combinations of these categories (Backer & Alain, 2012; Gregg, Irsik, & Snyder, 2014; McAnally et al., 2010).

Regardless of the method employed, a common finding is that a key determinant of change deafness is the allocation of attention. For example, when participants are explicitly instructed to listen for a change in a previously identified target, detection rates are markedly better than when they are either engaged in a secondary task or when they are simply instructed to listen to the stimulus (Backer & Alain, 2012; Eramudugolla, Irvine, McAnally, Martin, & Mattingley, 2005; Fenn et al., 2011; Neuhoff et al., 2015; Vitevitch, 2003). Eramudugolla et al. (2005) showed that listeners are poor at detecting the disappearance of a naturalistic sound from an auditory scene that contains more than four spatially separated sounding objects. However, when listeners knew the identity of the sound source that might disappear (e.g., a cello), they exhibited nearly perfect performance. These results suggest that under certain conditions, directed attention can eliminate change deafness (regardless of whether the change deafness stems from failures at encoding, retrieval, or comparison). More recent work using both valid and invalid cues suggests that attending widely to multiple objects in an auditory scene is an effective means of reducing change deafness (Irsik, Nederlanden, & Snyder, 2016).

Expertise and change detection

Other studies have shown that experts typically outperform novices when the content of the change is germane to the area of expertise (but see Canal-Bruland, Lotz, Hagemann, Schorer, & Strauss, 2011). Werner and Thies (2000) demonstrated that domain-specific expertise decreased the incidence of change blindness in the context of American football. They presented football experts and novices with football-related images in a "flicker paradigm" and found that experts detected the change in the image more quickly than novices. However, they found no difference in detecting changes to images that were not related to football. Similar studies have shown that experts detect visual changes better than novices in other domains including radiology (Beck, Martin, Smitherman, & Gaschen, 2013) and driving (Zhao et al., 2014). These behavioral findings are supported by work showing greater event related potential (ERP) effects for experts versus novices when detecting changes in a scene (Curran, Gibson, Horne, Young, & Bozell, 2009).

However, the advantage of expertise does not extend to changes that are not relevant to the domain of expertise and do not appear to transfer to other contexts (Gaspar, Neider, Simons, McCarley, & Kramer, 2013). The effects of expertise likely also depend on differences in how experts and novices allocate their attention in a specific domain. For example, one study examined change blindness in law enforcement officers and novice students (Smart, Berry, & Rodriguez, 2014). Participants were shown a video clip of a traffic stop where the driver was ordered out of the car. When the officer and driver briefly stepped out of the frame, the driver was replaced with another person. Law enforcement officers and students did not differ in their rates of change blindness for the driver, and students actually outperformed the law enforcement in detecting the change in clothing. The authors suggest that these results might be explained by the law enforcement officers' attention to more critical situational characteristics such as the driver's nervous behavior.

In audition, there has been little work on the relationship between change deafness and expertise. Agres and Krumhansl (2008) presented professional musicians and non-musicians with a brief melody, followed by a burst of noise, and then either the same or a slightly altered melody. They found an advantage of expertise with greater change detection among the musicians. Conversely, Neuhoff et al. (2014) found that linguistic expertise actually decreased performance in a change detection task. Native English–speaking and Native Spanish–speaking participants listened to a story in either their native language (expert) or an unfamiliar language (novice). Midway through the story, the voice reading the story was switched to another person in the same language. Novices who listened to the story in a language that they did not understand were significantly more likely to detect the change in the voice than native-language experts.

Although these results may seem contradictory, they can be explained by examining the attentional focus of each situation. In listening for differences between two melodies, musicians attended directly to the features of the stimulus that were changed (the arrangement of the notes in the melody). Thus, their expertise in processing melody gave musicians an advantage in detecting the change. However, speech contains both acoustic or "indexical" information about the identity of the talker and the semantic code or "meaning of the message" (Mullennix & Pisoni, 1990; Pisoni, 1997). Novices listening to a story in an unfamiliar language cannot access the semantic code and thus, can only attend to the indexical characteristics of the voice. Experts can process the semantic code, but this leaves fewer attentional resources available to detect changes in the acoustics of the voice. Thus, in the current work, we examine expertise because it can both facilitate or inhibit auditory change detection depending on the nature of the change and the attentional focus of the listener.

Dual-task vigilance

As a control condition in some change deafness experiments, listeners are alerted to the possibility of a change and then asked to monitor the auditory stimulus for the change (Fenn et al., 2011; Neuhoff et al., 2014; Neuhoff et al., 2015; Vitevitch, 2003). This manipulation is analogous to a vigilance task in which listeners monitor an auditory or visual stream of information for a particular target event (Binford & Loeb, 1966). Although the monitoring time is often shorter in a change deafness experiment than in a vigilance task, vigilance decrement effects (a decline in the ability to detect critical signals) have been found at durations of as little as 5 min (Helton & Russell, 2013).

In some respects, vigilance decrement is analogous to change deafness. In both cases, listeners fail to detect an above-threshold change or event. Under some conditions, the influence of a secondary task on vigilance can decrease detection performance, particularly if the secondary task is unrelated to the first and relies on the same cognitive resources as the vigilance task (Caggiano & Parasuraman, 2004; Epling, Russell, & Helton, 2016; Helton & Russell, 2015). Other work has shown that a secondary task can, in some cases, increase vigilance if the second task is related to the first (McBride, Merullo, Johnson, Banderet, & Robinson, 2007).

Although there is considerable literature on the effects of dual-task monitoring on vigilance, its effects on auditory change deafness have yet to be investigated. Most change deafness studies have asked participants to listen for a single change event, either in a complex auditory scene or in an isolated auditory stream (Barascud, Griffiths, McAlpine, & Chait, 2014; Gregg et al., 2014; Kawashima, 2015; Nieuwand & Van Berkum, 2005; Pavani & Turatto, 2008; Puschmann et al., 2013; Schnuerch et al., 2014; Sohoglu & Chait, 2016). As might be expected, change detection is significantly better when participants are alerted to the possibility of a change (Eramudugolla et al., 2005; Fenn et al., 2011; Neuhoff et al., 2015). However, given the performance costs of dual-task vigilance under some conditions, we might expect a decrement in change detection if listeners are asked to monitor an auditory stream for two different potential changes and those events are unrelated. Conversely, we might expect an increase in change detection performance if the to be detected events are related. In the current work, we examine the relationship between semantic and indexical information in a dual monitoring task.

The effects of listening for a specific semantic event in a single auditory stream while also monitoring the stream for a change in talker are unknown. Early work in this area has shown that changes in an unattended signal can go undetected when a participant is monitoring an attended signal (e.g., Cherry, 1953). However, this process involves filtering information from a secondary signal that is not relevant to the primary task. Previous work has suggested that limited cognitive and perceptual resources may underly many change deafness effects (Barascud et al., 2014; Vitevitch & Donoso, 2011). Thus, listening for a semantic event in a single auditory stream, even when alerted to a possible voice, change might increase change deafness.

We might expect then, that the highest rates of change deafness occur when listeners are simply asked to listen to an auditory stream and are not alerted to the potential for a change. We should find a significant decrease in change deafness when listeners are alerted to the possibility of a change. However, when listeners are asked to listen for two potential change events in a single auditory stream, we should find an intermediate level of change deafness. Knowing that a potential change event may occur should provide better performance than the "just listen" condition, but listening for two potential change events should create a performance decrement compared to participants who are instructed to listen for only one change event.

The current work

We investigate how allocating attention within a single auditory stream can influence change deafness in the context of a frequently occurring real-world event—a radio broadcast of a sporting event. Our goal was to examine the effects of directed attention under conditions in which listeners were directed to listen for either one or two events that might occur during the broadcast. In Studies 1 and 2, we presented listeners with the home team radio broadcast of a professional hockey game. During the 1-min audio clip, the home broadcast switched to the away team broadcast with a different announcer. In Study 1, we demonstrate change deafness when participants are instructed simply to listen to the broadcast. In Study 2, we experimentally examine the effects of directed and divided attention. In one condition, participants monitored the indexical characteristics of the voice by listening for an announcer change. In another condition, participants monitored both the indexical and semantic information by listening for an announcer change (indexical) and a goal scored (semantic).

In all three studies, we also examine the relationship between expertise and change detection. However, in Studies 1 and 2, we did not expect any effects of sports expertise because the change that occurred was in the voice of the announcer. This is outside the domain-specific area of expertise of sports experts and one in which both experts and novices would likely have similar knowledge and exposure. In Study 3, we created both an indexical and a semantic change in the speech signal by switching from a hockey broadcast to a broadcast of a professional basketball game. We hypothesized that experts would detect this change at a higher rate than novices because the change in sport fell within the domain of knowledge of the experts (Agres & Krumhansl, 2008; Gaspar et al., 2013; Smart et al., 2014; Werner & Thies, 2000).

Study 1

Method

Participants. The sample in Study 1 consisted of 65 participants (38 males) with an average age of 37.7 years (standard deviation [*SD*] = 13.5). All reported normal hearing. They were recruited via Amazon Mechanical Turk and as volunteers from online professional hockey forums. MTurk workers were paid US$0.30. All participants completed the study online. A wide variety of research has shown that samples from MTurk are more diverse and more representative of target populations, and that their reliability is as good as or better than that obtained from traditional undergraduate samples (Buhrmester, Kwang, & Gosling, 2011; Holden, Dennie, & Hicks, 2013; Mason & Suri, 2012; Paolacci, Chandler, & Ipeirotis, 2010). Mturk samples have also been employed in previous change deafness studies (Neuhoff et al., 2014; Neuhoff et al., 2015).

Materials. The auditory stimulus was recorded from two radio broadcasts (home and away) of a single National Hockey League game between the New Jersey Devils and the Nashville Predators (see Supplemental Materials). Audio across all studies was obtained from online broadcasts of satellite radio, recorded using Audacity 1.3.13 at a sampling rate of 44.1 kHz, and saved as 320 kbs mp3 files. The duration of the audio clip was 60 s and occurred at the close of the first period of play. The clip began with the New Jersey broadcast. At the 23-s mark in the clip, there was a very brief lull in the flow of the game that allowed the signal to be smoothly switched to the Nashville broadcast featuring a different announcer. Because the crowd noise and sounds of the game on the ice were common to both broadcasts, the announcer change was unobtrusive. Subjectively, the first announcer had a slightly higher pitch voice than the second. This was confirmed when the recordings were matched for overall root mean square (RMS) power and submitted to Praat (Boersma & Weenink, 1992) for analysis of mean fundamental frequency and amplitude variation. Speaker A had a mean fundamental frequency of 173 Hz (*SD* = 51.5 Hz), and Speaker B had a mean fundamental frequency of 157 Hz (*SD* = 44.6 Hz). Listeners adjusted the signal volume to comfortable listening level. Amplitude variation for each speaker was as follows: Speaker A: *SD* = 6.4 dB, Speaker B: *SD* = 8.8 dB. The announcers were seated in the same section of the arena calling the same game, so there were no noticeable differences in ambient noise.

Design and procedure. Participants were asked to listen carefully to the 1-min radio broadcast and told that they would be asked some questions at the end. There were no other instructions. At the conclusion of the audio clip, all participants answered three standard change deafness questions modeled after Vitevitch (2003): (1) *Did you notice anything unusual about the radio broadcast?* (2) *Was the first half of the radio broadcast the same as the second half of the radio broadcast?* (3) *Was the voice in the first half of the broadcast the same as the voice in the second half of the broadcast?* Responses to Question 3 were the primary units of analysis. Responses were constrained yes/no answers. However, those who responded

Table 1. Study 1: Correlations among measures of expertise and change detection ($N=65$).

Variables	Detected voice change	Freq. listening to hockey	Visualization	Playing experience	Rules knowledge
Detected voice change		−0.01	−0.15	−0.05	−0.16
Freq. listening to sports			0.63**	0.38**	0.55**
Visualization				0.29*	0.64**
Playing experience					0.37**
M (*SD*)	0.15 (0.36)	27.7 (32.3)	48.5 (31.3)	0.13 (0.35)	1.8 (1.6)
Range	0–1	0–100	0–100	0–1	0–4

SD: standard deviation.
*$p<0.05$, **$p<0.01$.

"yes" to Question 1 received the open-ended follow-up question "*What was unusual?*" We then asked four multiple-choice questions designed to test expertise and knowledge of the rules of hockey: (1) *Hockey is played with how many players on each side?* (2) *When a player crosses the opposing blue line before the puck and touches it, what is it called?* (3) *A goaltender's blue area where he stands is called?* (4) *How many penalty minutes are issued for a minor penalty?* The number of correct answers was treated as a single variable "rules knowledge." This was followed by three questions designed to test previous experience with hockey. (1) *How often do you watch or listen to hockey games?* (2) *How would you rate your ability to visualize what is happening from a radio broadcast of a hockey game?* (3) *Have you ever played on an organized hockey team?* Questions 1 and 2 were answered using an unmarked visual analog scale that appeared on the screen with the anchors "*Never–Very Often*" for Question 1 and "*Very Poor–Excellent*" for Question 2. Scale values were hidden from the participants but coded as 0-100. Question 3 was a yes/no response.

To guard against naive participants simply looking up the answers to our expertise questions, we examined the total time each participant took to complete the survey. As a conservative measure, we removed any participant with survey duration of greater than 1.5 *SD* above the mean. This resulted in the removal and replacement of five participants. The resulting sample had a mean survey duration of 3 min 11 s (*SD* = 1 min 4 s). No participant had survey duration greater than 5 min. This included the mandatory durations of the radio broadcast (1 min) and sound verification signal (9 s), resulting in an average of 2 min and 2 s for participants to answer 14 questions (including demographic information), or 8.7 s per question.

Results and discussion

Only 10 of our 65 participants responded "no" to the primary change deafness question "*Was the voice in the first half of the broadcast the same as the voice in the second half of the broadcast?*" indicating that 85% did not detect the change in announcer. Three participants responded "yes" to Question 1: *"Did you notice anything unusual about the radio broadcast?"* All three of these participants indicated in the follow-up question that the announcer had changed. A total of 23 participants responded "no" to Question 2: "*Was the first half of the radio broadcast the same as the second half of the radio broadcast?"* However, 15 of these respondents subsequently indicated that the announcer had not changed. We found no significant relationship between any measure of expertise and change detection. However, we did find medium to large significant correlations among all of our measures of expertise. Bivariate correlation coefficients are shown in Table 1.

The 85% error rate under these conditions is relatively high compared to many other studies. Some previous work has demonstrated error rates from around 30% to 50% (Asutay & Vastfjall, 2014; Gregg et al., 2014; Neuhoff et al., 2015; Vitevitch, 2003). Obviously, the discriminability of the two stimuli, the specific stimuli, and instruction conditions affect these rates (Dickerson & Gaston, 2014). For example, in the context of a telephone conversation, Fenn et al. (2011) found that change deafness rates for two voices in some conditions were over 90%. In Study 2, we examine the discriminability of the two announcers by explicitly instructing participants to listen for a change.

We found no significant correlation between hockey expertise and change detection. However, the change that occurred in the stimulus was an indexical one. The "semantic flow" of the game was not changed or interrupted in a way that might have given experts an advantage in detecting the change. Hockey experts and novices presumably have the same amount of experience processing the indexical characteristics of a voice. Thus, the change in the stimulus did not lend itself to giving the experts an advantage. We revisit this issue in Study 3.

Study 2

In Study 1, the large majority of our participants failed to notice a change in announcer during the radio broadcast of a hockey game. These high rates of error could simply be due to difficulty in discriminating between the two voices. In Study 2, we examine this possibility by testing the ability to detect the change under two different sets of instructions. In the first condition, participants are explicitly directed to listen for a change in announcer. We also examine the effects of divided attention in a condition where listeners are asked to listen for a change in announcer and also asked to listen for a goal scored in the game.

We hypothesized that change detection performance would be best when listeners were instructed to simply listen for a change in announcer. Even though participants in the divided attention condition are specifically instructed to listen for a change in announcer, they are also tasked with attending to the semantics of the broadcast by listening for a goal scored. Focusing attention on the semantic characteristics of the speech signal can make it more likely that a change in the indexical characteristics of the talker goes unnoticed. We also examined the relationship between expertise and change detection as in Study 1.

Method

Participants. The sample consisted of 130 participants (75 males) with an average age of 35.7 years ($SD = 11.3$). All reported normal hearing. They were recruited via Amazon Mechanical Turk (MTurk) and as volunteers from online professional hockey forums. MTurk workers were paid US$0.30. All participants completed the study online. None had participated in Study 1.

Materials. The auditory stimulus was the same as that used in Study 1.

Design and procedure. Participants were assigned to two different instruction groups. The first group was instructed to listen to the broadcast and told that there might be a change in announcer at some point. While the broadcast played, a button on the screen was displayed with the words "announcer change." Participants were told to click the button as quickly as possible only if they heard a different announcer. The second group was told that the announcer may change and that a goal may be scored. While the broadcast played, two buttons were displayed on the screen. One said, "announcer change," and the other said, "goal scored." Participants were instructed to click the appropriate button as quickly as possible only if they heard the relevant event. Participants then answered the same questions about expertise that were presented in Study 1. A total of 10 participants were removed and replaced for excessive survey duration by the same criteria used in Study 1. Mean survey duration was 2 min 57 s ($SD = 34$ s).

Results and discussion

When instructed only to listen for a change in announcer, 44 of 65 participants detected the change. This indicates an error rate of 32%, which is significantly lower than the 85% error rate in Study 1 where listeners were not alerted to the possibility of a change $\chi^2(1) = 36.6$, $p < 0.001$, $\Phi = 0.53$. However, 32% of our participants were still not able to detect a change even when they were alerted to the possibility of a change. If these changes are truly below threshold for these listeners, then the true rate of change deafness for these stimuli is more likely around 53% (85% in the "just listen" condition of Study 1—32% who were unable to detect the change when alerted to the possibility).

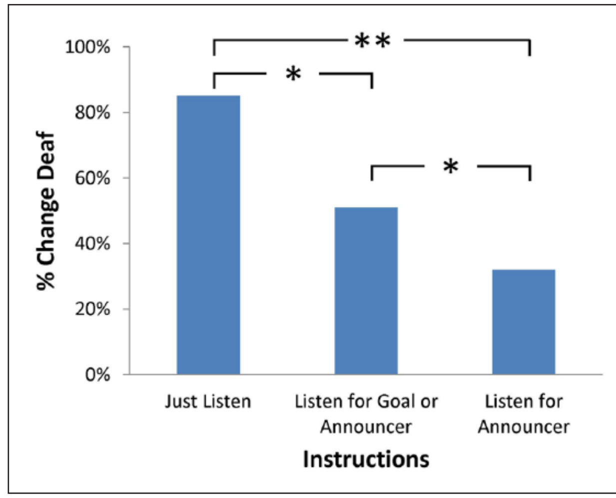

Figure 1. Percentage of participants who experienced change deafness under three different instruction conditions in Study 1 (*Just listen*) and Study 2 (*Listen for a goal scored or an announcer change*), (*Listen for an announcer change*).
$^{*}p < 0.05$, $^{**}p < 0.01$.

When listeners were asked to listen simultaneously for the possibility of a goal scored and for an announcer change, only 32 detected the change in announcer. This indicates an error rate of 51% and is significantly greater than those who were instructed to listen only for a change in announcer $\chi^2(1) = 4.6$, $p = 0.03$, $\Phi = 0.19$ (see Figure 1). We calculated bivariate correlations and once again found no significant relationship between measures of sports expertise and change detection (see Table 2). These results are consistent with our findings in Study 1. We find no relationship between change detection and expertise when the indexical change occurs outside the domain-specific expertise of hockey experts.

The results suggest that attending to both the indexical characteristics of the voice and the semantics of the game for a possible goal has associated attentional and performance costs even if listeners are expecting a change. Participants who were asked to listen only for an announcer change could do so without closely following the action of the game. Those who were tasked with listening for both an announcer change and a goal needed to attend to both, and their performance in detecting the change suffered.

Dual-task vigilance research has shown that when observers monitor two unrelated signals, vigilance

Table 2. Study 2: Correlations among measures of expertise and change detection ($N = 130$).

Variables	Detected voice change	Freq. listening to hockey	Visualization	Playing experience	Rules knowledge
Detected voice change		0.04	–0.04	–0.10	0.12
Freq. listening to sports			0.60**	0.20*	0.69**
Visualization				–0.06	0.55**
Playing experience					0.21*
M (*SD*)	0.58 (0.50)	29.3 (33.2)	51.5 (31.2)	0.07 (0.25)	2.0 (1.5)
Range	0–1	0–100	0–100	0–1	0–4

SD: standard deviation.
*$p < 0.05$, **$p < 0.01$. Correlations calculated for each instruction group separately also showed no significant relationship between expertise and change detection.

performance suffers (Caggiano & Parasuraman, 2004; Epling et al., 2016; Helton & Russell, 2015). Our results support these findings. Even though our listeners had to attend to only one auditory stream, the indexical characteristics of the speaker were unrelated to the semantic events being described. Attending to both resulted in decreased change detection performance. Previous work has suggested a model of limited cognitive and perceptual resources underlying change deafness effects (Barascud et al., 2014; Vitevitch & Donoso, 2011). Our results are consistent with this view.

Study 3

In Studies 1 and 2, we found no relationship between sports expertise and change detection. This is likely because expertise in sports did not provide any particular advantage in detecting the indexical change in announcer, even though the topic of the speech was sports related. However, we might expect a relationship with expertise when the nature of the change is semantic and related to the area of expertise. In Study 3, we hypothesized that experts would show better change detection performance than novices when the sport being broadcast was changed. Support for this hypothesis comes from work in vision that shows when the object of change is pertinent to the game, experts are better at detecting the change (Werner & Thies, 2000). Thus, we presented listeners with a radio broadcast of a hockey game that was unobtrusively switched to a broadcast of a basketball game and assessed the relationship between sports expertise and change detection. We compare this to a control condition that replicates Study 1, but asks more general sports expertise questions in order to directly compare change deafness and expertise effects in the two conditions.

Method

Participants. The sample in Study 3 consisted of 160 participants (93 males) with an average age of 33.9 years ($SD = 10.3$). All reported normal hearing. They were recruited via Amazon Mechanical Turk (MTurk) and were paid US$0.30 to complete the study online. None had participated in Study 1 or 2. Two participants failed to complete the demographic and expertise questions, and their results were excluded from the analysis.

Materials. Participants were assigned to one of two groups that heard either the same change stimulus used in Study 1 (hockey–hockey) or a new stimulus that was composed of a radio broadcast of a hockey game that switched to a radio broadcast of a basketball game (hockey–basketball). The acoustic characteristics of the hockey–hockey broadcast were the same as those in Study 1, with the exception that the clip was truncated to 44 s in order to match the duration of the hockey–basketball clip. The hockey portion of the hockey–basketball broadcast was the same as the first segment (Speaker A) used in Study 1. The basketball portion was from a National Basketball Association (NBA) game between the Memphis Grizzlies and the San Antonio Spurs and was 21 s in duration. The two portions of the hockey–basketball recording were matched for overall RMS power, and the basketball portion was submitted to Praat (Boersma & Weenink, 1992) for analysis of mean fundamental frequency and amplitude variation. The basketball announcer had a mean fundamental frequency of 196 Hz ($SD = 36.9$ Hz). Participants adjusted the volume of the signal to a comfortable listening level. Amplitude variation had an *SD* of 4 dB. Ambient noise differed between the two broadcasts because of different arenas and the typical sounds of the different games (e.g., skates and sticks on the ice versus “sneaker squeaks” on the hardwood). Differences in these “sounds of the game” may tap into a sports expert’s domain of expertise. The switch from hockey to basketball occurred after 23 s.

Design and procedure. All participants were asked to listen to the radio broadcast and told that they would be asked some questions at the conclusion. There were no other instructions. At the conclusion of the audio clip, all participants answered the same change deafness questions used in Study 1. The hockey–basketball group was also asked

Table 3. Study 3: Correlations among measures of expertise and change detection (hockey–hockey announcer change) ($N=80$).

Variables	Detected voice change	Freq. listening to sports	Visualization	Playing experience
Detected voice change		0.19	–0.04	0.01
Freq. listening to sports			0.39**	0.18
Visualization				–0.27*
M (*SD*)	0.18 (0.38)	56.5 (31.1)	60.6 (26.3)	0.50 (0.50)
Range	0–1	0–100	0–100	0–1

SD: standard deviation.
$^{*}p<0.05$, $^{**}p<0.01$.

Table 4. Study 3: Correlations among measures of expertise and change detection (hockey–basketball change) ($N=78$).

Variables	Detected voice change	Detected sport change	Freq. listening to sports	Visualization	Playing experience
Detected voice change		0.47**	0.30**	0.27*	0.33**
Detected sport change			0.36**	0.26*	0.21
Freq. listening to sports				0.76**	0.52**
Visualization					0.67**
M (*SD*)	0.33 (0.47)	0.47 (0.50)	48.8 (37.1)	56.2 (31.9)	0.46 (0.50)
Range	0–1	0–1	0–100	0–100	0–1

SD: standard deviation.
$^{*}p<0.05$, $^{**}p<0.01$.

one additional question: *Was the sport in the first half of the broadcast the same as the sport in the second half of the broadcast?* We then asked three general questions designed to test previous experience with sports. (1) *How often do you watch or listen to sports?* (2) *How would you rate your ability to visualize what is happening from a radio broadcast of a game?* (3) *Have you ever played on an organized sports team?* Questions 1 and 2 were answered using the same visual analog scale used in the previous studies with the anchors "*Never–Very Often*" for Question 1 and "*Very Poor–Excellent*" for Question 2. Question 3 was a simple yes/no response.

Results and discussion

After listening to the hockey–hockey stimulus with a change in announcer, only 19 of 80 participants detected the change. This indicates an error rate of 83% and replicates the results of Study 1 (85%). In the hockey–basketball group, 26 of 78 participants noticed the change in announcer, indicating an error rate of 67% that was significantly lower than the hockey–hockey group $\chi^2(1)=5.2$, $p=0.02$, $\Phi=0.19$.

We confirmed that there were no significant differences in expertise between the two groups by running independent samples *t*-tests on each expertise question between groups. None of the tests were significant. Then, to examine the relationship between expertise and change detection in each condition, we ran separate Pearson correlations for each group. As in Study 1, we found no significant correlations between change detection for announcers and sports expertise in the hockey–hockey group (see Table 3). However, when the sport changed from hockey to basketball, we found significant medium-sized correlations between each of our measures of expertise and change detection for announcer (see Table 4). Participants with greater sports expertise were more likely to detect a change in announcer than those with less expertise. Those participants who reported more frequent listening and viewing of sports and better visualization of sports on the radio were also more likely to detect the sport change from hockey to basketball.

In the hockey–basketball group, we also asked whether listeners detected the change in sport. We found that 53% of our participants failed to notice this change and 46% failed to notice both changes in sport and announcer. In addition, 20% of our participants noticed the sport change but not the announcer change, and 6% detected the change in announcer but failed to notice that the sport being broadcast had changed (see Figure 2).

Our results show that when change occurs that is germane to a domain-specific area of expertise, listeners are more likely to detect that change. A simple change in a speaker's voice is not sufficient for recruiting the sports expertise effect, even when the topic of the speech is about sports. The findings mirror work in vision that shows domain-specific expertise in sports affords an advantage in visual change detection when the change is related to the area of expertise Werner and Thies (2000). Like these findings, the current results suggest that expertise can enhance

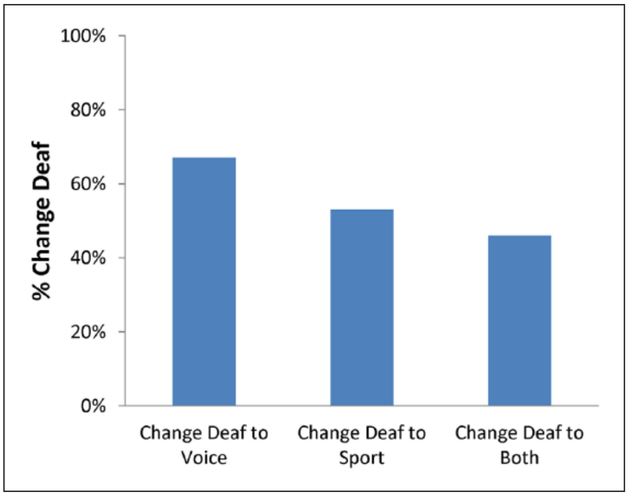

Figure 2. Percentage of participants who failed to detect an announcer change, sport change, or both in Study 3 when the signal changed from a hockey game to a basketball game.

change detection of semantic characteristics of the domain-specific signal. In the ****hockey–hockey condition, the semantic characteristics of the signal did not change. The continuation of the same game was called by each of the two different announcers. However, the change from hockey to basketball was a semantic change, and the ability to detect this kind of change is related to sports-specific expertise.

General discussion

In three studies we showed that listeners exhibit high rates of change deafness for a change in announcer during a radio broadcast of a sporting event. In Study 1, 85% of listeners who were not cued to the possibility of a change failed to detect the announcer change in a hockey game. When alerted to the possibility of a change in Study 2, the rate dropped to 32%. However, if listeners were alerted to the potential for a change but also asked to listen for changes in both the semantic and indexical characteristics of the speech signal, the error rate increased to an intermediate value of 51%. In Studies 1 and 2, we found no relationship between sports expertise and detecting a change in announcer. However, in Study 3, we made a semantic change in the signal from a hockey game to a basketball game and found that those with greater sports expertise were more likely to detect the change.

The expertise results are consistent with previous change detection studies in vision showing that experts in a domain are better at detecting unexpected changes in domain-specific semantic content, but do not differ from novices in change detection outside of that domain (Gaspar et al., 2013; Smart et al., 2014; Werner & Thies, 2000). Agres and Krumhansl (2008) similarly showed that professional musicians are more sensitive to changes in brief melodies than non-musicians, particularly when the melodies conformed to the stylistic norms in which the musicians were trained. In Studies 1 and 2, the "semantic flow" of the game did not change, and experts and novices performed similarly. However, in Study 3, the semantic content changed dramatically, and expertise was positively correlated with change detection. These results support previous findings on expertise in change deafness and suggest that auditory changes that violate cognitive schemata are more likely to be detected by listeners with greater expertise in these areas.

Our results are also consistent with previous work that shows linguistic processing can affect change deafness for voices (Neuhoff et al., 2014; Vitevitch, 2003). Our participants tasked with listening for two potential changes still only had to monitor one speech stream. Nonetheless, monitoring semantic content produced greater change deafness to the indexical change. However, previous studies that have shown this lexical/semantic tradeoff in change detection have typically occurred under conditions where listeners were not expecting a change in speaker. In Study 2, we showed that attending to semantic information can reduce the detection of changes in the indexical information even when listeners are alerted to the possibility of an indexical change. The simultaneous focus of attention on both dimensions of the speech signal incurs a cost in detecting change in one of those dimensions even if the change is anticipated.

Dual-task vigilance research has shown that the influence of a secondary task can either increase or decrease performance on the primary task depending on the degree to which the secondary task is related to the first (Caggiano & Parasuraman, 2004; Epling et al., 2016; Helton & Russell, 2015; McBride et al., 2007). The current results suggest a dissimilarity between monitoring semantic and indexical information. This is likely because the indexical qualities of the speaker were unrelated to the semantic event being monitored. Taken together, these results suggest that although indexical and semantic information may be processed in different ways (Mullennix & Pisoni, 1990; Pisoni, 1997), they likely rely on the same cognitive resources (Barascud et al., 2014; Neuhoff et al., 2014; Vitevitch, 2003; Vitevitch & Donoso, 2011).

The nature of perceptual representation

Our results also provide further evidence that our experience of the environment is not veridical (Hoffman et al., 2015). We are biased to see and hear the world in ways that are more likely to keep us safe. Indeed, a growing body of experimental and computational work shows that some perceptual biases can bestow adaptive value that would exceed that provided by an isomorphic perceptual representation of the world (Feldman, 2013; Gagnon, Geuss, & Stefanucci, 2013; Haselton et al., 2009; Haselton & Buss, 2000; Hoffman et al., 2015; Mark, Marion, & Hoffman, 2010; Neuhoff, 1998, 2001, 2016; Neuhoff, Planisek, & Seifritz, 2009; Stefanucci et al., 2012).

Failures in change detection are similar perceptual distortions that seem to be shaped by similar processes. For example, recent work demonstrates greater change detection for objects that suddenly appear in an auditory scene than for objects that disappear, or for sounds with a negative emotional valence compared to a neutral valence (Asutay & Vastfjall, 2014; Constantino et al., 2012). Both appearing sounds and negatively valenced sounds can pose a greater threat, and these kinds of changes are detected at a higher rate. Similarly, change blindness research on "animate monitoring" shows that participants are better at change detection for animals than for inanimate objects (Altman, Khislaysky, Coverdale, & Gilger, 2016; Calvillo & Hawkins, 2016; Calvillo & Jackson, 2014; New, Cosmides, & Tooby, 2007; Wang, Tsuchiya, New, Hurlemann, & Adolphs, 2015).

Change detection failures provide striking examples of our inability to create a faithful representation of the world around us. Limited cognitive resources restrict our ability attend to everything in the environment. How we attend, and to what we attend, have been shaped by exposure to external stimuli both ontogenetically in the case of expertise, and phylogenetically. Future change detection work that incorporates both types of previous experience might be particularly instrumental in providing further insight into the phenomena.

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Supplementary Material

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