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Change deafness and object encoding with recognizable and unrecognizable sounds ☆

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ABSTRACT

Change deafness is the failure to notice changes in an auditory scene. In this study, we sought to determine if change deafness is a perceptual error, rather than only a reflection of verbal memory limitations. We also examined how successful encoding of objects within a scene is related to successful detection of changes. Event-related potentials (ERPs) were recorded while listeners completed a change-detection and an object-encoding task with scenes composed of recognizable sounds or unrecognizable temporally scrambled versions of the recognizable sounds. More change deafness occurred for the unrecognizable, compared to recognizable sounds, indicating that change deafness is a perceptual error and not solely a product of verbal memory. ERPs from both the recognizable and unrecognizable scenes revealed an enhanced P3b (at PZ/1/2, POZ/3/4 from 350 to 750 ms) to detected changes, a marker that conscious change detection has occurred. Recognizable scenes resulted in an enhanced T400 (at T8/TP8, C6/CP6 from 315 to 660 ms) to detected changes, possibly indicating activation of established memory representations. Unrecognizable scenes elicited an enhanced P3a (at FCZ/1/2 from 280 to 600 ms) to detected changes, indicating enhanced orienting to acoustic change. Performance on the object-encoding task revealed that change deafness was reduced, but not eliminated, when performance on the object-encoding task was accurate.

1. Introduction

Natural auditory environments are filled with a substantial amount of acoustic information that often overlaps in time, frequency, and location (Bregman, 1990). Accurately perceiving sound in real-world environments is challenging because of the complexity of the physical signal and because of limited perceptual and cognitive abilities (e.g., Broadbent, 1958; Cherry, 1953; Cowan, 2005; Treisman, 1964). One surprisingly large perceptual error that has been demonstrated to occur during natural scene perception is the phenomenon of change deafness (e.g., Gregg & Samuel, 2008; Vitevitch, 2003; for reviews see Snyder & Gregg, 2011; Snyder, Gregg, Weintraub, & Alain, 2012), an analog to the visual phenomenon of change blindness (e.g., O'Regan, Rensink, & Clark, 1999; Rensink, O'Regan, & Clark, 1997; Simons & Levin, 1998; for a review see Simons & Rensink, 2005). Change deafness is the failure to notice often obvious changes occurring in an auditory scene, such as a trumpet tune changing to a bird chirping (e.g., Eramudugolla, Irvine, McAnally, Martin, & Mattingley, 2005). Recent behavioral (e.g., Eramudugolla et al., 2005; Gregg & Samuel, 2008, 2009) and neurophysiological (Gregg & Snyder, 2012; Puschmann, Weerda, Klump, & Thiel, 2013; Puschmann, Sandmann, et al., 2013) investigations have revealed some of the factors that seem to influence when change deafness occurs. Here, we address two major issues in change deafness research that have not been resolved. First, there is a question of whether poor object-encoding is a cause of change deafness. Second, there is the question of whether change deafness is at least partly a failure of fundamental auditory sensory processing or simply a reflection of verbal memory limitations. In this study, we aim to address both of these questions, which are critical to understanding the nature and cause of change deafness.

Behavioral investigations of change deafness have shown that it occurs with speech (e.g., Vitevitch, 2003) and environmental sounds (e.g., Eramudugolla et al., 2005) and that it occurs when scenes are interrupted by silence or noise and when there is no interruption at all (Pavani & Turatto, 2008). For example, Eramudugolla et al. (2005) presented interrupted scenes of auditory objects, such as instruments and animal sounds, and found change deafness that increased in scenes with larger numbers of

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sounds. Spatially separating the sounds in a scene does not seem to improve detection performance compared to scenes with no spatial cues (Gregg & Samuel, 2008), and change detection performance in studies that have utilized spatial cues (e.g., Eramudugolla et al., 2005; Puschmann, Sandmann, et al., 2013) is similar to detection performance in studies that have not implemented spatial separation of the sounds. The acoustics of a scene appear to be a critical component of change deafness, as performance improves when the objects within scenes have distinct acoustic properties (see Gregg & Samuel, 2008, 2009; Gregg & Snyder, 2012). Recent ERP investigations have suggested that successfully segregating the acoustics of the post-change scene plays an important role in reducing change deafness, and that this segregation occurs at a sensory processing level (Gregg & Snyder, 2012; Puschmann, Sandmann, et al., 2013).

Cognitive factors also play an important role in change deafness. For example, attention to the object that changes across scenes reduces change deafness (Backer & Alain, 2012; Eramudugolla et al., 2005). Also, a late parietal P3b-like response is enhanced during successful detection of changes (Gregg & Snyder, 2012; Puschmann, Sandmann, et al., 2013), suggesting that conscious change detection initiates a memory-updating process (Polich, 2004). Finally, listeners are more likely to miss changes within the same semantic category, such as a small songbird chirp changing to a seagull squawk (Gregg & Samuel, 2009). Though no change detection study, to our knowledge, has investigated the brain regions involved in semantic influences on missing changes, neuroscience research on recognizing and categorizing environmental sounds has indicated that sounds are categorized quite early in processing (as soon as 70 ms after sound onset, Murray, Camen, Gonzalez Andino, Bovet, & Clarke, 2006; see also De Lucia, Tzovara, Bernasconi, Spierer, & Murray, 2012) and that environmental sound categorization involves bilateral activation in the middle temporal gyri and in the right superior temporal sulcus (Lewis, Wightman, Brefczynski, Phinney, Binder, DeYoe, 2004; see also DeLucia, Clarke, & Murray, 2010).

1.1. The role of object-encoding

One potential reason that change deafness occurs could be a failure to encode or maintain representations of the objects within scenes. There is mixed evidence for this explanation: McAnally et al. (2010) distinguished between object-encoding on detected and not-detected change trials. They found that object-encoding was near ceiling when changes were detected, but object-encoding was at chance level when changes were not detected. However, a different study found that change deafness occurred despite the fact that objects from both scenes were relatively well encoded (Gregg & Samuel, 2008). It should be noted that the extent of change deafness that occurred in McAnally et al. was actually quite modest. They only obtained 15% change deafness for scene sizes of 4 objects, whereas Gregg and Samuel obtained 45% change deafness for scene sizes of 4 objects. One potential reason for the discrepancy across studies may be that the nature of the task in McAnally et al. was different than most other studies of change deafness. In their study, a changed scene consisted of an object that was missing, rather than an object replaced by a different object as in Gregg and Samuel. Despite the task differences, the results of McAnally et al. do question the extent to which object-encoding failures contribute to change deafness, which warrants further investigation. Given that no other study has recorded object-encoding and auditory change detection performance on the same trials, we did so in the present study. We predicted failures in object-encoding to account for some portion of change detection failures.

1.2. The role of verbal memory

Although there is a wealth of information on the properties and potential causes of change deafness, it has been suggested that reports of change deafness with environmental sounds actually reflect verbal memory limitations, rather than a fundamental auditory perceptual error (Demany, Trost, Serman, & Semal, 2008; see also Constantino, Pinggera, Paranamana, Kashino, & Chait, 2012). Here, verbal memory means remembering a list of the names of the sounds: verbal encoding likely occurs in memory and language areas of the brain. Brain activity during the encoding of verbal material, such as written words, has been found to be left lateralized, activating the left medial temporal lobe (e.g., Jansen et al., 2009; Kelley et al., 1998; Powell et al., 2005), while the encoding of non-verbal material, such as unfamiliar faces, is typically associated with right-lateralized activity (Kelley et al., 1998; Powell et al., 2005). Auditory sensory memory, on the other hand, is the representation of an auditory stimulus that involves brain structures early in the auditory pathway (e.g., Alain, Woods, & Knight, 1998; Sabri, Kareken, Dzemidzic, & Lowe, 2004; Schönwiesner et al., 2007). Recent brain imaging studies have found that detection of a change in an auditory discrimination task, which requires sensory memory, results in increased activation near primary auditory cortex (e.g., Sabri et al., 2004; Schönwiesner et al., 2007). And, patients with damage to temporal/parietal regions show decreased performance on an auditory discrimination task and a decreased auditory deviant detection brain response, the mismatch negativity (Alain et al., 1998). These decreases in performance and brain activity occurred when stimuli were presented to the ear contralateral to the lesioned hemisphere, suggesting that sensory memory is predominantly localized in the auditory cortex contralateral to ear of presentation.

The claim that change deafness is a product of verbal memory limitations is important to evaluate because this would imply that investigations of change deafness are not related to auditory perceptual processes. Evidence that change deafness is a product of verbal memory has been provided by the finding that change detection of pure tones making up non-recognizable chords is quite good, and superior to visual change detection (e.g., Demany, Semal, Cazalets, & Pressnitzer, 2010; Demany et al., 2008).

There are problems with the claim that change deafness arises solely from verbal memory limitations (see Demany et al., 2008). First, there are recent data inconsistent with this claim: Puschmann and colleagues have found change deafness to non-recognizable bandpass noise rhythms (Puschmann, Sandmann, et al., 2013; Puschmann, Weerda, et al., 2013). In addition, Gregg and Snyder (2012) found that sensory-level activity is enhanced during successful change detection in recognizable sounds. Puschmann and colleagues found similar sensory-level involvement in the absence of consciously detected changes in recent ERP (Puschmann, Sandmann, et al., 2013) and brain imaging (Puschmann, Weerda, et al., 2013) studies with non-recognizable sounds. Another potential problem for the claim that change deafness is a product of verbal memory is that the stimuli used by Demany and colleagues (Demany et al., 2008, 2010) may not be appropriate for measuring change deafness: the stimuli may have been perceived as a single chord, rather than several different components making up a chord. In addition, the claim by Demany and colleagues relies on psychophysical data from stimuli that may allow for specialized frequency-change detectors that are maximally sensitive to very small frequency changes in otherwise static sounds. In summary, the claim that change deafness is a product of verbal memory cannot be entirely true, but it is important to carefully evaluate the issue of how much semantic or verbal information may aid change detection using alternative, unrecognizable stimuli.