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Attribute capture in the precedence effect for long-duration noise sounds

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Abstract

Listeners perceptually fuse the direct wave from a sound source with its reflections off nearby surfaces into a single sound image, located at or near the sound source (the precedence effect). This study investigated how a brief gap presented in the middle of either a direct wave or simulated reflection is incorporated into the fused image. For short (<9.5 ms) delays between the direct (leading) and reflected (lagging) waves, no sound was perceived from the direction of the lagging wave. For delays between 10 and 15 ms, both sounds were perceived, but the gap was heard only on the leading side. When the gap was only in the correlated lagging sound at short delays, it also was perceived as occurring on the leading side. Moreover, gap detection thresholds were the same for gaps in the leading and lagging sounds, suggesting that the perception of the gap was not suppressed, but rather incorporated into the leading sound. Finally, scalp event-related potentials were not associated with the precedence effect until the gap occurred. This suggests that cortical mechanisms are engaged to maintain fusion when attributes in direct or reflected waves change.

Keywords: Precedence effect; Fusion; Reverberant environment; Correlation; Gap; Event-related potential

1. Introduction

In a reverberant environment, each sound source produces both a direct wavefront and numerous filtered and time-delayed reflections from the walls, ceilings and other surfaces. When the delay between the direct wave and a reflected wave is sufficiently long and the reflected wave is sufficiently intense, the reflected wave is perceived as a distinct auditory event (an echo), whose perceived location is usually different from that of the source. However, when the delays between the direct wavefront and its reflections are short (e.g., 1–10 ms or more, depending on the stimulus), the auditory system somehow gives "precedence" to the direct wavefront over its reflections so that the listener hears only a single fused sound whose point of origin is perceived to be at or near the location of the sound source. This phenomenon is called the "precedence effect" (Clifton and Freyman, 1989; Freyman et al., 1991; Shinn-Cunningham et al., 1993; Wallach et al., 1949; Zurek, 1980; for reviews see Blauert, 1997; Li and Yue, 2002; Litovsky et al., 1999; Zurek, 1987).

Abbreviations: B&K, Brüel & kjær; ERP, event-related potential; HATS, head and torso simulator; IAC, Industrial Acoustic Company; RO, right loudspeaker was turned on only; L/U, left leading/uncorrelated; L/C, left leading/correlated; R/C, right leading/correlated; TDT, Tucker–Davis technologies

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The precedence effect reduces listeners' perception of multiple images by perceptually grouping correlated acoustic waveforms from different directions, thereby avoiding the perception of multiple sound images when only one source is present. Furthermore, because the fused image is perceived as originating at or near the location of the source, localization errors are reduced in reverberant environments. In experimental environments, the "direct" and "reflected" waves are usually produced by two spatially separated sound sources, and the shortest time delay between a direct and a reflected wave that produces a separate echo on certain percentage of experimental trials (usually between 50% and 80%) is called the echo threshold (Blauert, 1997, pp. 224–225).

Since a simulated reflection in an experimental environment is not heard as a separate auditory event when the lead/lag delay is below the echo threshold, it has been assumed that some inhibition or attenuation of information in reflected sounds, such as contralateral inhibition (Blauert, 1997, pp. 230–233), must take place in the precedence effect. For instance, a prevalent explanation is that the directional information associated with the reflected wave is suppressed (Blauert, 1997; Liebenthal and Pratt, 1999; Litovsky and Shinn-Cunningham, 2001; Rakerd et al., 2000; Yin, 1994; Zurek, 1980). This suppression hypothesis has dominated the search for neural correlates of the precedence effect. In most of the related physiological studies using either anesthetized or unanesthetized animals, suppressed neural responses to the lagging sound in the presence of the leading sound were treated as the neural correlates of the precedence effect (Fitzpatrick et al., 1995, 1999; Liebenthal and Pratt, 1999; Litovsky, 1998; Litovsky and Delgutte, 2002; Litovsky and Yin, 1998a,b; Litovsky et al., 1997; Yin, 1994).

However, suppression of the directional information in the reflection does not mean that the reflected wave is not heard because listeners are aware of the presence of reflections and even changes in them. For example, Freyman et al. (1998) have shown that listeners are as sensitive to intensity decreases in the lagging sound as to intensity increases in the leading sound, indicating that intensity information in the reflection is not suppressed. Also, hearing a reflection while presumably suppressing its directional information raises some puzzles as to how the perceptual system incorporates reflected waves into the percept of a single auditory event. For example, it is not clear how the intensities of a source and its reflections blend to determine the loudness of the "fused" sound image. Finally, Hartung and Trahiotis (2001) have developed a model for describing how monaural peripheral processing without an inhibitory mechanism may contribute to data obtained in binaural "precedence" experiments that use binaural pairs of transients as stimuli. Hence, it is evident that there is more to the precedence effect than simple inhibition.

Most studies on the precedence effect have used idealized brief acoustic stimuli, such as clicks or transient noise bursts, to avoid or reduce temporal overlap between the leading and lagging sounds (for a review see Litovsky et al., 1999). However, acoustic stimuli under normal circumstances are usually complex and last for more than a few hundred milliseconds. Therefore, it is important to study how the precedence effect works for long-duration stimuli, and determine how attributes that belong to reflections, and indeed may be unique to them, are incorporated into the fused image of the source.

In the present study, a transient gap, as a probe attribute, was inserted into an otherwise continuous steady-state broadband noise. Because this gap could be in the source (the leading sound) only, the reflection (the lagging sound) only, or both source and reflection, it should be easier to determine how this attribute of the direct wave and/or the reflection is detected and incorporated in the overall percept of the sound.

Introducing a single gap into either the leading or the lagging sound (but not both) is also interesting from the point of view of top-down control over the precedence effect. For example, a gap only in the lagging but not in leading stimulus is inconsistent with the lagging stimulus being an echo (a gap in a natural reflection should have its origin in the sound source), and could lead to a breakdown in the precedence effect. Moreover, if the gap is in the lagging stimulus only, and the leading and lagging stimuli remained fused into a single percept, will the listener perceive a break in the fused stimulus, or will the gap in the lagging stimulus be suppressed so that the listener hears a continuous fused stimulus? To investigate issues such as these, listeners were asked to describe their experience to the gap, which was introduced into the middle of either the leading or lagging sound.

As mentioned earlier, most neurophysiological studies on the precedence effect have mainly focused their efforts on determining the brainstem mechanisms involved in lag suppression in experimental animals (Fitzpatrick et al., 1995, 1999; Litovsky, 1998; Litovsky and Delgutte, 2002; Litovsky and Yin, 1998a,b; Litovsky et al., 1997; Yin, 1994). However, there is more to precedence than simple suppression of the location information of the lagging stimulus. For example, several studies have shown that listeners' knowledge and expectations about the room acoustics can strongly affect the precedence effect (Clifton, 1987; Clifton and Freyman, 1989; Clifton et al., 1994; Freyman et al., 1991). Repeated presentations of the leading and lagging clicks, which are not perceived to be fused at the beginning, can eventually cause fusion to occur, suggesting that following continued exposure to a reverberant environment, listeners can build up a new representation of